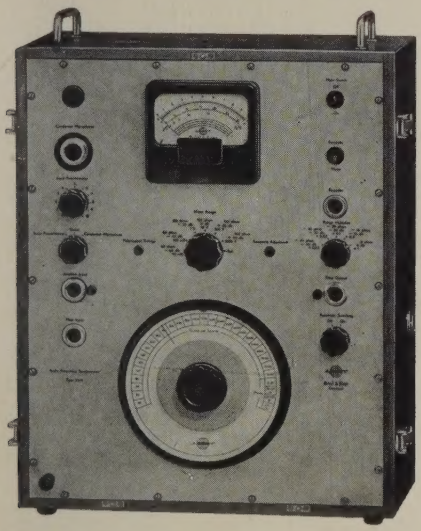
2110

INSTRUCTIONS AND APPLICATIONS

Audio Frequency Spectrometer Type 2110



A Spectrum Analyzer dividing the frequency range 35 c/s to 35 kc/s into 30 one third octave bands. Frequency band selection can be carried out manually or automatically by means of an external motor drive. By means of a switch the built-in rectifier and meter circuit can be switched to measure either the arithmetic average, the true R.M.S. or the peak value of the input signal. Connections for Condenser Microphone and Level Recorder. The instrument also contains two low noise amplifiers and the internationally standardized weighting networks for sound level measurements.

Acoustic standing wave apparatus
Artificial ears
Artificial voices
Audio frequency spectrometers
Audio frequency voltmeters
Automatic A. F. spectrum recorders
Automatic frequency response recorders
Beat frequency oscillators
Condenser microphones
Deviation bridges
Distortion measuring bridges
Electronic counters
Frequency analyzers
Frequency measuring bridges
Frequency response tracers
Hearing aid test apparatus
Heterodyne voltmeters
Level recorders
Megohmmeters
Microphone amplifiers
Microphone calibration apparatus
Noise sources
Polar diagram recorders
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Audio Frequency Spectrometer

Type 2110

JANUARY 1959

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Description.

General.

The Audio Frequency Spectrometer Type 2110 is primarily designed for electrical, electro-acoustical and vibration measurements and analyses in the audio frequency range.

It consists basically of an input amplifier, a filtersystem and an output amplifier, as shown in the block diagram fig. 2, thus enabling selective measurements to be carried out.

The bandwidth of the filters (except for the weighting networks) is $^1/_3$ octave, which makes the instrument well suited for the frequency analysis of

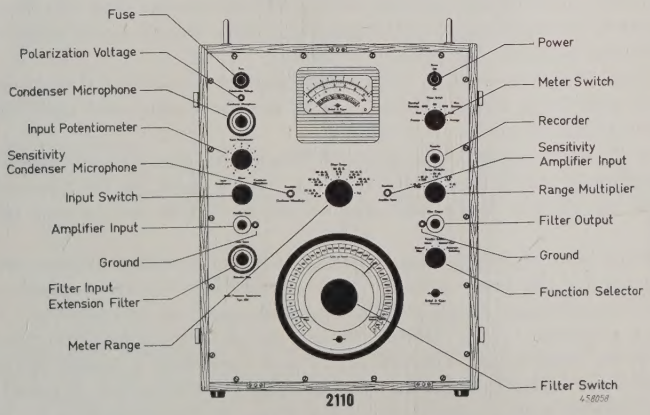


Fig. 1. Drawing of Type 2110 with control knob identification.

noise and vibration signals, as well as for selective measurements of reverberation decay curves.

The weighting networks are designed to meet the specifications given by the German DIN 5045 and the American A.S.A. Z 24.3 standards for objective sound level measurements. When switched to "Lin. 2—35000 c/s" the frequency characteristic of the Spectrometer is linear to within ± 0.3 db in the range 5—20000 c/s and to within ± 0.5 db from 2 c/s to 35000 c/s.

A switch in the instrument meter circuit enables the true r. m. s., the arithmetic average and the peak value of the signal to be measured.

The power supply contains the necessary rectifiers and filters for operating the amplifiers as well as for operating the B & K Condenser Microphones with Cathode Followers and the Vibration Pick-up Preamplifier.

The Spectrometer is designed for mechanical connection to the Level Recorder Type 2304. By synchronizing the frequency sweep of the filter switch of Type 2110 with the paper drive of the Level Recorder, a complete frequency-amplitude diagram of complex signals can be recorded automatically on preprinted, frequency calibrated recording paper.

When desired, the Spectrometer and the Level Recorder are also delivered as a compact unit:

The Audio Frequency Spectrum Recorder, Type 3310. A drawing of this unit is shown in fig. 19.

Description of the Input Amplifier.

The input amplifier consists of three stages and is provided with two different input sockets, one of which is seven poled and corresponds to the plug on the B & K Condenser Microphones and Preamplifiers.

The other input socket accommodates a 14 mm coaxial plug and can be connected to the input circuit of the amplifier, either directly or via a variable potentiometer used for relative measurements.

By means of a three-position input switch marked "Condenser Microphone", "Direct", and "Input Potentiometer", one of the above-mentioned three input facilities can be chosen.

When the input switch is in position "Condenser Microphone" the input socket marked "Condenser Microphone" is to be used. In the two other positions the voltage to be measured should be fed to the 14 mm input socket.

From the input switch the signal voltage is fed to a voltage divider, which is operated by the knob marked "Meter Range" on the front panel and contains five steps of 20 db with a total impedance of 2.2 megohms. The different positions of the "Meter Range" switch are marked for several values of the input voltage between 10 mV and 1000 volts. A further position marked "Ref." serves to check the sensitivity of the instrument. A stabilized voltage, derived from a current stabilizing device, is then applied to the grid of the first tube of the amplifier.

The two first stages of the amplifier consist of resistance-capacitance coupled triodes, while the third stage is built as a cathode-follower. A great amount of negative feed-back is introduced to stabilize the amplifier and ensure a low source impedance, approx. 12 Ω, to be coupled to the filter system.

A terminal marked "Filter Input-Extension Filter" parallels the filter input, enabling either the preamplifier or the filters to be used separately, the filter output being available across the "Filter Output" terminals.

The harmonic distortion produced in the input amplifier is smaller than one part in thousand.

The heaters of the amplifier tubes are supplied from a bridge rectifier. In this way a hum level lower than two microvolts, referred to the grid of the input tube, has been achieved.

As the tubes and the corresponding coupling components are mounted on a rubber-suspended chassis there is no disturbance from microphony in the amplifier, even when a signal of only a few microvolts is being measured.

Description of the Filters.

The 30 filters have center frequencies at $^1/_3$ octave distances. The center frequencies are 40 - 50 - 63 - 80 - 100 - 125 - 160 - 200 - 250 - 315 - 400 - 500 - 630 - 800 - 1ooo - 1250 - 1600 - 2ooo - 2500 - 3150 - 4ooo - 5ooo - 6300 - 8ooo - 10ooo - 12500 - 16ooo - 20ooo - 25ooo - 31500 c/s. The figures are the so-called preferred numbers which are standardized in most countries and are rounded-off values. The exact values are numbers whose logarithms are multiples of o.1, i.e. whose mantissae are exactly o.1, o.2, o.3 etc.

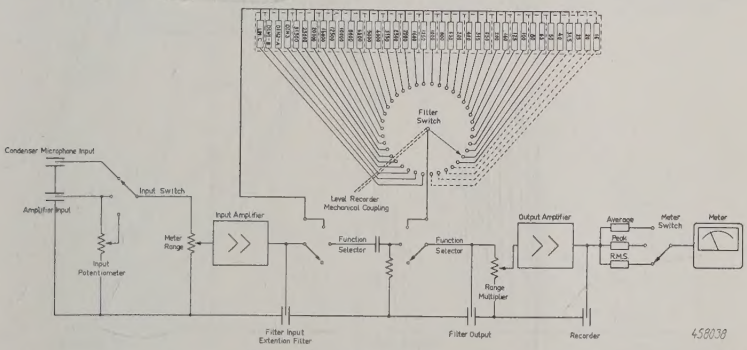


Fig. 2. Block diagram of the Spectrometer.

A single filter consists of 3 resonant circuits coupled together as shown in fig. 3. The first two resonance circuits have a Q of approx. 5 and is loosely coupled to the second with a coupling factor of the order of magnitude k = o.05.

The first two circuits will give rise to a two-topped frequency response as shown in fig. 4 left, while the third gives a single top which raises the valley between the two tops, so that a resultant curve as shown in fig. 4 right is obtained with a relatively flat passband and steep sides. Because the quality factor is dependent on the frequency, the two tops will not have the same height. To obtain the desired passband, the third resonant frequency must therefore be placed unsymmetrically, and the resultant response curve will have two humps, a broad one and a narrow one.

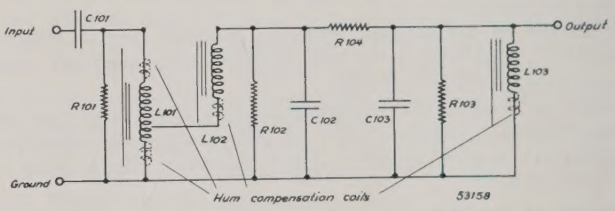


Fig. 3. Schematic diagram of a single one third octave filter unit.

The input impedance curve of all the filters together will be a wave shaped curve varying between approx. 500 ohms and 2000 ohms, so that the impedance is high at the center frequencies and low at the band-limits. See fig. 5. The input voltage will therefore also vary up and down if the output impedance of the preamplifier is not made low. In the Spectrometer an output impedance of approx. 12 ohms has been obtained. The voltage across the filters will thus only vary approx. 1 %.

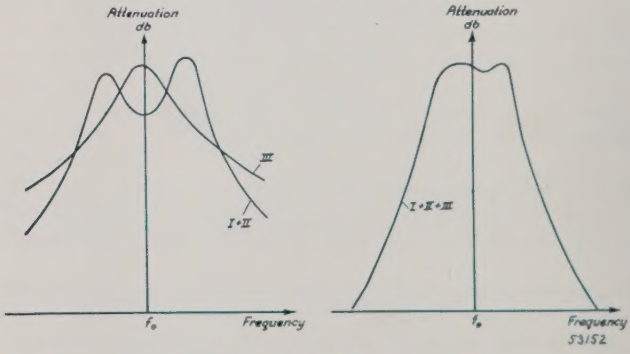


Fig. 4. Frequency characteristics showing the functioning of the filter unit.

When it is desired to use the filters only, connections should be made, as previously mentioned, to the terminals marked "Filter Input-Extension Filter" and "Filter Output". The input impedance across the "Filter Input-

Extension Filter" terminals varies between approx. 500 and 2000 Ω, and the external source impendance must therefore be of the order of 10—20 Ω. The maximum voltage to be supplied should be 1 volt.

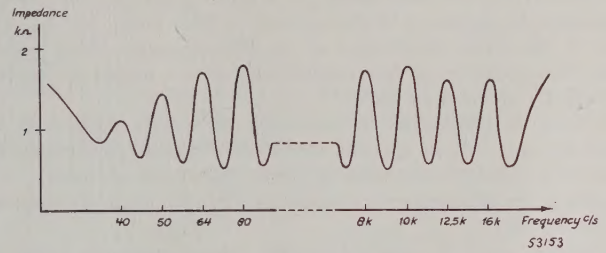


Fig. 5. Variation in input impedance of the filter section.

The impedance coupled to the "Filter Output" terminals should be high. A resistor of a approx. 1—2 megohms paralleled by a capacitor of max. 20—30 pF is suitable. (The filters can be used even if these requirements are not satisfied, but the filter curves will then be more or less spoiled).

The filters are adjusted so that within the passband the peak to valley ratio is less than 1 db, normally about ½ db.

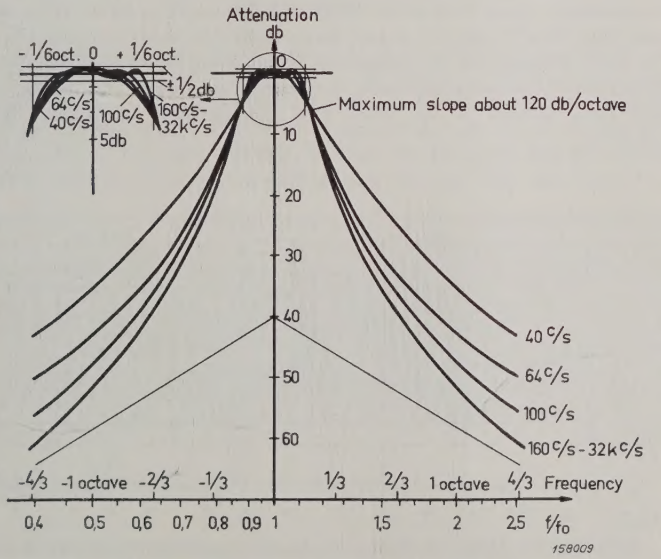


Fig. 6. Detailed filter characteristics.

The attenuation in the passband is accordingly adjusted to be 0 or —½ db, respectively.

The frequency response curve of a filter is flat to within ± ½ db over approx. ¼ octave. At the band limits, i.e. ⅙ octave from the center frequency, the attenuation is approx. ± 3 db, normally a little lower. See fig. 6. However, due to the rather steep slope of the filter curves at these points, the frequency characteristics of two neighbouring filters cannot be expected to intersect exactly at the 3 db point.

This is easy to understand as displacing the center frequencies of the two filters by only 1 % in opposite directions will cause the intersection to take place at a point 1.7 db higher or lower than the 3 db point.

If the width of the filter curve is changed by 1 %, the point of intersection is changed by 0.2 db.

The attenuation at ± ⅓ octave from the center frequency is 20—21 db, and at ± 1 octave about 52 db.

The figures given are valid for the filters in the upper audio frequency range.

However, it has been impossible to obtain sufficiently high quality factors for the coils at frequencies below 160 c/s, without lowering the stability or making the filters bigger and heavier. The filter curves will therefore not be of the same quality at lower frequencies, as can be seen from fig. 6 and 7. There will be only one top, and the "flat" part is about ⅙ octave. The attenuation is up to 4 db at the band limits, from 12 to 20 db at ± ⅓ octave and from 35 to 50 db at 1 octave away from the center frequency. As far as the lower frequencies are concerned, it has been found that magnetic fields from nearby mains transformers or electrical machinery can induce considerable hum voltages in the coils, even though these are placed in sealed pot-cores.

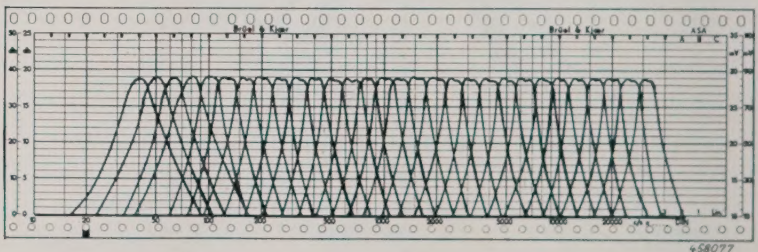


Fig. 7. Frequency characteristics for the one third octave filters.

Compensation coils, as shown in fig. 3, are therefore wound outside the pot-cores whereby the hum voltage is reduced by a factor of 10 or more.

With regard to the weighting networks, these are arranged as shown in fig. 8. The following curves are obtained (see fig. 9):

Frequency c/s	30	60	125	250	500	1k	2k	4k	8k	20k
DIN 3	—52	—40	—27	—15	—5					
DIN 2 ASA.A	—38	—27	—17	— 9	—2	0	+1.5	+1.5	—8	—20
DIN 1 ASA.B	—19	—10	— 5	— 2	—1					

Tolerance ± 2 db, except at 1 k/c where it is ± 1 db. The curves satisfy both the German DIN 5045 and the American ASA Z 24.3 standards for objective sound level measurements.

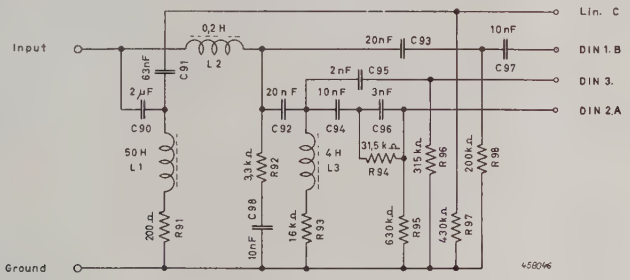


Fig. 8. Schematic diagram of the weighting networks for sound level measurements.

The switching from one filter to the next is accomplished by means of a rotary switch, and the centre frequency of the filters is indicated on a large illuminated scale. This scale is calibrated from 16 c/s although the Spectrometer only contains filters with centre frequencies from 40 c/s to 31.5 kc/s. The calibration of the scale, however, is based on the use of Extension Filter Type 1619 (ZS 0145) which is available as a separate unit and consists of

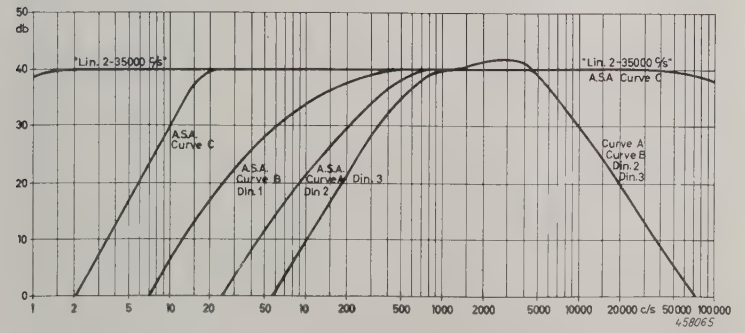


Fig. 9. Typical frequency characteristics of the weighting networks (and "linear").

4 one third octave filters with centre frequencies of 16 – 20 – 25 and 32 c/s.

When measurements are taken by reading off the instrument meter, the switch is normally operated by hand. However, provision is made for automatic switching and the method employed is described under "Automatic Recording of Voltage Analysis" p. 15.

The rotary switch has 50 different positions. One complete revolution of the switch thus means 50 successive switchings. Only 34 positions of the switch are employed for connections to the built-in filters, 16 positions being unused.

These 16 points are connected to a terminal board at the back of the instrument chassis and can, when desired, be used for connecting additional external filters. 6 of the points are led to the seven poled socket marked "Filter Input-Extension Filter", to which the Extension Filter Type 1619 can be connected directly. When Type 1619 is not used, or when it is built into the cabinet of the instrument itself (this is possible for the combined units Type 3310 and 3320 only) a special adapter is inserted in the "Filter Input-Extension Filter" socket, transforming the seven poled jack into a 14 mm screened coaxial socket.

Description of the Output Amplifier.

The output amplifier also consists of three stages, and the input impedance is 1.46 MΩ.

In the input circuit a voltage divider, operated by the knob marked "Range Multiplier" on the front panel and containing 4 steps of 10 db, is inserted. With the "Range Multiplier" switch in position x1 (0 db), the amplification of the output amplifier is 10 times. Maximum amplification is obtained with the "Range Multiplier" switch in position x 0.01 (40 db), and is then 1000 times.

The output amplifier is provided with negative feed-back, the amount of which may be varied by means of two potentiometers. The sensitivity of the apparatus can thus be adjusted, the reference voltage being used as control voltage. One of the potentiometers is in circuit when the "Input Switch" is in position "Condenser Microphone", the other when the switch is in either of the two positions "Direct" or "Input Potentiometer". Separate sensitivity adjustment is thus obtained for sound measurements and voltage measurements, which is very convenient for the practical use of the Spectrometer. The potentiometers can be operated with the aid of a screwdriver through holes in the front panel marked "Sensitivity-Condenser Microphone" and "Sensitivity-Amplifier Input".

The output circuit of the amplifier is connected both to the output terminals marked "Recorder" and to the rectifier and meter circuit.

The "Recorder" terminals are provided for connection to headphones, oscillograph or level recorder etc., or it can be connected to the compressor input of the Beat Frequency Oscillator Type 1014. The output impedance is smaller than 50 ohms, and a maximum voltage of approx. 30 volts is available.

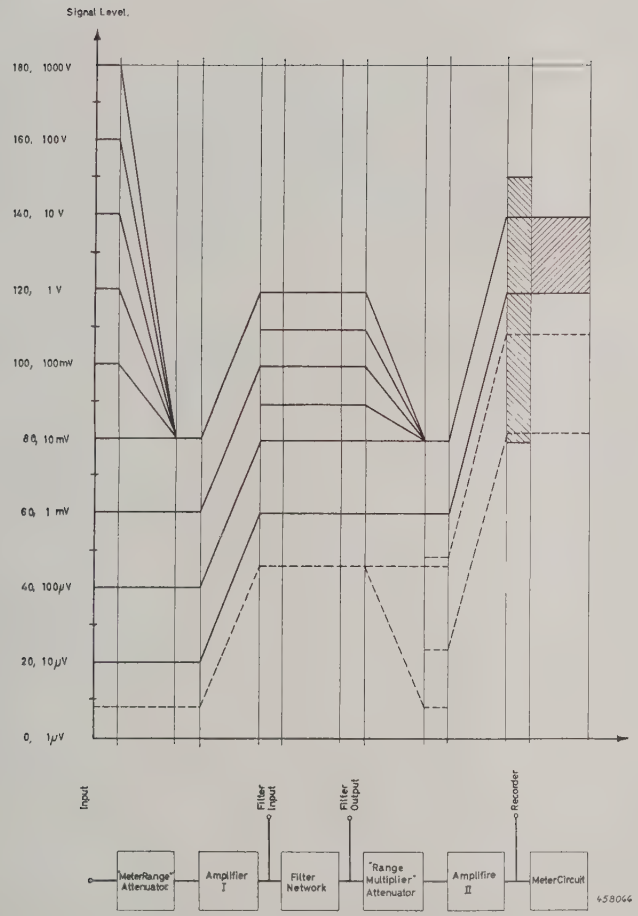


Fig. 10. Sketch showing the signal levels at different points in the Spectrometer. The dotted lines indicate the noise levels.

A switch in the rectifier circuit enables either the peak, the arithmetic average or the true r. m. s. value of the input signal to be measured. Furthermore, two different damping characteristics of the meter can be selected, one of which is in accordance with the standards for sound level measurements. Because this damping characteristic will cause the meter pointer to "vibrate" at frequencies lower than 10 c/s, a greater damping can be chosen for the measurement of very low frequency signals.

The r. m. s. rectifier circuit is designed to approximate the square-law curve by means of a number of straight line portions. The resulting curve enables the true r. m. s. value of signals with crest factors up to 5 (14 db) to be measured to within ± 0.5 db of the theoretically correct value.

The peak rectifier circuit is designed to measure half the peak-to-peak value of the input signal. This should be borne in mind when peak measurements are carried out on unsymmetrically shaped signals.

When the instrument meter gives full scale deflection, a voltage of 10 volts is available across the "Recorder" terminals.

The meter itself is gradated 0—10 and 0—31.5 as well as 0 to 20 db. Furthermore, scales permitting the direct reading of acoustic absorption coefficients are provided. These scales should be used when measurements are taken with the Standing Wave Apparatus Type 4002.

When the "Range Multiplier" switch is in position "x 1 (0 db)" the signal to noise ratio for full scale deflection on the meter is better than 60 db for any setting of the "Meter Range" switch, see also fig. 10.

By using any of the other four positions of the "Range Multiplier" switch the signal to noise ratio for full meter deflection decreases the same number of db as the amplification is increased.

To obtain the best ratio between signal- and noise-voltage, the "Range Multiplier" switch should therefore, during measurements, be set to give as low amplification of the output amplifier as possible, preferably "x 1 (0 db)". However, when measurements are carried out where filters are inserted between the two amplifier sections care must be taken not to overload the input amplifier.

The "Function Selector" should therefore first be set to position "Linear" and the amplification of the instrument be adjusted as described above. This is necessary to make sure that no large voltage components exist outside the band limits of the filters. When the filters are inserted such voltage peaks will not be detectable on the meter and might therefore easily overload the input amplifier. If even weak components of a frequency spectrum have to be measured, the amplification should, for the reason given above, be increased by means of the "Range Multiplier" switch until a suitable deflection is obtained on the meter.

When it is desired to read the result of selective measurements directly on the instrument meter, the "Function Selector" is set to "Internal Filter", and the Spectrometer filter switch operated by hand. In case the measure

ments are to be recorded on the Level Recorder Type 2304 in the form of a spectrogram, however, the "Function Selector" switch should be set to "Automatic Switching".

A further position of the switch is marked "External Filter" and is used when the two amplifier sections of the Spectrometer are coupled to an external filter.

The input signal voltage which gives full deflection on the meter is found by multiplying the number of mV indicated on the chosen position of the "Meter Range" switch by the multiplication factor indicated on the position of the "Range Multiplier" switch. If, for example, the "Meter Range" switch is in position "1 V (100 db)" and the "Range Multiplier" switch is in position "x 1 (0 db)" full deflection on the meter occurs for 1 volt $\times$ 1 = 1 volt.

Using the full amplification of the apparatus full deflection on the meter corresponds to an input signal voltage of 10 mV $\times$ 0.01 = 100 μV.

Description of the Power Supply.

The power supply section of the apparatus contains three rectifiers, one of which supplies the heater current to the apparatus itself. Another supplies heater current to the amplifier tubes of the B & K Condenser Microphones or Preamplifiers via the "Condenser Microphone" input jack, and a third one supplies the necessary anode voltages for the amplifiers as well as the polarization voltage for the microphone cartridge of the Condenser Microphones. The anode voltage is stabilized with the aid of two neon tubes. A bushing marked "Polarization Voltage" on the front panel of the apparatus makes it possible to measure quickly the polarization voltage for the microphone cartridges. Because of the relatively high source resistance a voltmeter with a resistance of around 20000 Ω/Volt should be used for this measurement. The voltage can be adjusted by means of a screwdriver operated potentiometer on the back of the instrument. The adjustment range is 150 to 250 volts. In case the Spectrometer is used in connection with a Condenser Microphone of the Type 4111, the polarization voltage should be 150 Volts. When used with one of the Condenser Microphones 4131 or 4132, however, the polarization voltage should be 200 Volts. Before the instrument leaves the factory the voltage is adjusted to 200 Volts.

The apparatus should be operated from a 50 to 400 c/s power line and can be adjusted for mains voltages of 115 - 127 - 150 - 220 or 240 Volts. The power consumption is approx. 50 watts. Adjustment for the different supply voltages can be carried out with the aid of a screwdriver through a hole in the back plate of the apparatus. A printed dial mounted on the adjuster shows the value of the supply voltage to which the apparatus is set. The primary side of the power transformer is fused, the fuse being placed in a fuse-holder on the front panel of the apparatus.

If the apparatus is to be operated from an accumulator, or from other DC supplies, the use of a vibrator or a rotary converter is necessary.

Operation.

General.

Make sure that the instrument is adjusted to the appropriate power supply voltage. It can then be switched on with the aid of the switch marked "Power" on the front panel. The light on the meter and filter switch scale comes on immediately, and after a warming-up time of about two minutes the apparatus is ready for use.

Voltage Measurements.

The apparatus might be used as a linear tube voltmeter in the audio frequency range with a maximum sensitivity at full scale deflection of 100 microvolts.

Before the actual measurements are carried out, however, the sensitivity of the instrument should be checked by means of the reference voltage, the "Function Selector" switch being set to position "Linear", "Meter Range" to "Ref.", "Range Multiplier" to "x 1 (0 db)", and the meter switch to "Standard Damping, RMS".

After 20—30 seconds the current regulator tube will be in stable condition and the meter should now show a deflection to the red mark on the scale. Possible deviations should be corrected by means of the potentiometer marked "Sensitivity-Amplifier Input" on the front panel, which has to be operated by a screwdriver.

The voltage to be measured is fed to the "Amplifier Input" socket and the input switch is set to position "Direct". The input resistance is then 2.2 megohms and the input capacity approx. 20 pF. The "Function Selector" is kept in position "Linear", and the desired voltage range chosen by means of the "Meter Range" and "Range Multiplier" switches. If possible, the "Range Multiplier" switch should be in position "x 1 (0 db)", the reason for this being given under "Description of the Output Amplifier", p. 10.

If desired, the voltage measured can be recorded on a level recorder, for example Type 2304, which should then be connected to the output socket marked "Recorder".

Analysis of Audio Frequency Voltages.

When complex voltages are analyzed, care should be taken not to overload the amplifiers (see also "Description of the Output Amplifier", p. 10).

With the "Function Selector" switch in position "Linear" the instrument can be adjusted as described under "Voltage Measurements", until a suitable deflection is obtained on the meter.

The actual analysis can then be carried out setting the filter switch to the desired band and the "Function Selector" to "Internal Filter". If weak components of a frequency spectrum are to be measured, the amplification of the instrument can be increased by means of the "Range Multiplier" switch.

When possible the "Meter Range" switch should not be used to increase the sensitivity, as the input amplifier might then easily be overloaded. An overloading of the amplifier would result in generation of undesirable distorton and combination-tones thereby causing inaccurate or false measurements.

Automatic Recording of Voltage Analyses.

Employing the Level Recorder Type 2304 the analysis of complex signals can be carried out automatically and a written record of the measurements obtained in the form of a spectrogram.

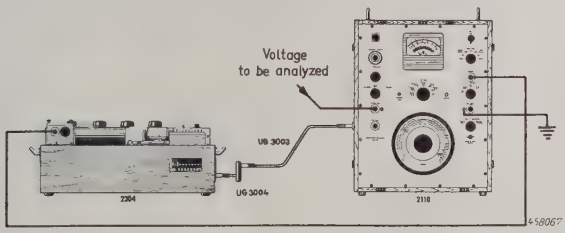


Fig. 11. Measuring arrangement for automatic recording of voltage analyses.

To calibrate the measuring arrangement, the following procedure can be employed:

1. Connect the instruments as shown in fig. 11 and set the control knobs on the Spectrometer according to the following scheme:
   (The use of Speed Multiplier UG 3004 is necessary to obtain synchronous drive of the Spectrometer filter switch and the Level Recorder paper.)
2. "Input Potentiometer": Any position.
3. "Input Switch": "Direct".
4. "Meter Range": "Ref.".
5. "Filter Switch": "40" (c/s).
6. "Power": "On".
7. "Meter Switch": "Standard Damping, RMS".
8. "Range Multiplier": "x 0.3".

9. "Function Selector": "Linear".
10. Allow two minutes warm-up time. The meter-pointer should now deflect to maximum on the meter scale. Possible deviations should be corrected by turning the potentiometer marked "Sensitivity Amplifier Input" with the aid of a screwdriver through the hole in the front panel of the instrument. Set the control knobs on the Level Recorder as follows (see also fig. 12):

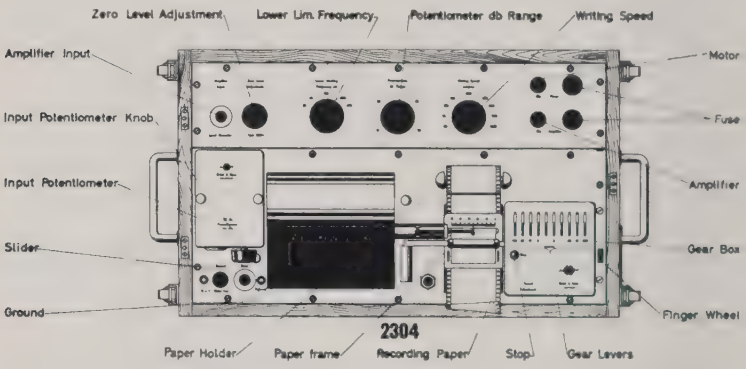


Fig. 12. Drawing of the Level Recorder Type 2304 with control knob identification.

11. "Zero Level Adjustment": The knob should be turned fully counter clockwise.
12. "Lower Lim. Frequency": "20 c/s".
13. "Potentiometer db Range": "50".
14. "Writing Speed": "100".
15. "Motor": "Off".
16. "Amplifier": "On".
17. "Slider": "Record".
18. Input Potentiometer Knob: The knob should be turned until the deflection of the Level Recorder stylus is 40 db.
    Remarks: The above settings on the Level Recorder is based on the use of a 50 db input potentiometer.

To record the spectrogram of the signal being analyzed proceed as follows:

19. Supply the Level Recorder with the desired type of preprinted recording paper. To insert the paper in the Level Recorder the paper frame (fig. 12) is pulled carefully upwards. The paper roll is then mounted in the paper holder and the paper arranged so that the perforation corresponds to the "teeth" in the paper drive wheel. (By mounting the

paper in the paper holder care should be taken that the paper holder axle is "locked" in its correct position!)

The paper frame is now pressed down on the paper until a small "click" is heard. It will then be locked by means of a snap lock arrangement.

To shift the paper all gear levers must be disengaged. This condition is obtained by pressing the button marked "Stop" on the gearbox, and the paper can then be shifted by means of the small finger wheel to the right of the gear box. (Do never shift the paper by pulling it directly!)

20. Engage any of the levers on the Level Recorder gearbox between 0.1 mm/sec. and 0.01 mm/sec.
21. Switch the switch marked "Motor" to "On". The setting of the control knobs on the instruments should be the same as stated before, with the following exceptions:
22. Set "Range Multiplier" switch on Type 2110 to "x 1".
23. Turn "Meter Range" switch counter clockwise until the Level Recorder stylus shows a deflection between 40 and 50 db.

    If this deflection of the stylus cannot be obtained even with the "Meter Range" switch in position "10 mV" the amplification is increased by turning the "Range Multiplier" switch counter clockwise.
24. Set the knob marked "Writing Speed" on the Level Recorder to any desired position between 100 mm/sec. and 700 mm/sec.
25. Release the Level Recorder paper drive by pressing the button marked "Stop".
26. Shift the recording paper by means of the "Finger Wheel" (fig. 12) until the position of the stylus is within the shaded area in fig. 14. according to item 28. (See also table below.)
27. Switch off the Level Recorder motor with the aid of the switch marked "Motor".

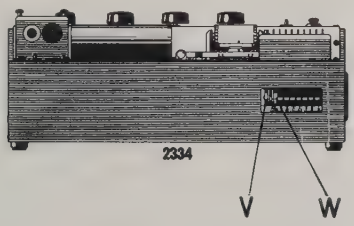


Fig. 13. Front view of the Level Recorder.

28. Shift the wheel marked W on fig. 13 to position A or B. (Position A corresponds to a paper speed of 10 mm/sec., and position B to a paper speed of 3 mm/sec. In normal automatic analysis only these two speeds will be of importance.)

To shift the position of the wheel the use of a screwdriver (or knife blade) may be necessary. With the aid of the screwdriver (knife blade) the wheel is moved to its proper position. When the position is reached the wheel will be automatically locked onto the axle by means of a snap lock arrangement.

To make sure that the wheel W is in its correct position the following rule of thumb may be employed:

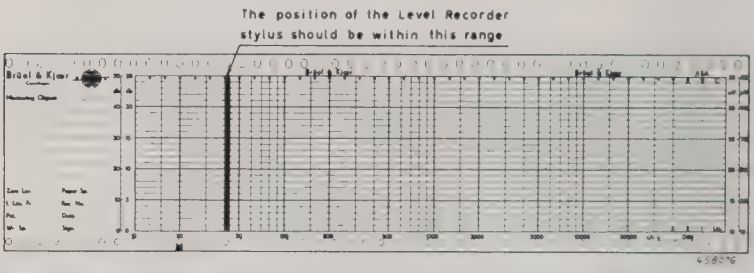


Fig. 14. Synchronization of the paper: The Level Recorder Stylus should be within the shaded area. (40 c/s filter).

W is in position A when it is moved so far to the left that it touches the hub of the wheel V, see fig. 13. To reach the position B it should be moved a little to the right, and when the snap lock is engaged it should not be possible to rotate W by "pushing" it with a finger.

29. Engage the lever on the Level Recorder gearbox marked 10 mm/sec. or 3 mm/sec., depending on which position is chosen for the wheel W, according to item 28. (See also table below.)

Paper Speed	100	30	10	3	1	0.3	0.1	0.03	0.01	0.003	—
Corresponding position of W	—	—	A	B	C	D	E	F	G	H	J

Table showing the connection between paper speed and position of the wheel W in fig. 13 for correct synchronization between the "Filter Switch" of 2110 and the preprinted, frequency calibrated paper for 2304

The figures are valid when the Speed Multiplier UG 3004 is used only (fig. 11). UG 3004 has a gear ratio 24 : 40

30. Set the "Function Selector" switch of the Spectrometer to position "Automatic Switching". By doing so the filter switch might move one position in the clockwise direction. It is then necessary to reset the filter switch to the original position.

31. Start the Level Recorder motor by switching the "Motor" switch to "On".
32. The spectrogram will now be recorded automatically, and when a complete diagram is recorded the Level Recorder motor is stopped and the paper slip containing the spectrogram cut off for evaluation.
    To cut off the paper, that part which contains the recorded Spectrogram is bent upwards and backwards towards the rear of the Level Recorder. By quickly pulling the paper to the right it is now cut on the Level Recorder paper frame.
33. Note down on the paper the position of the "Meter Range" and "Range Multiplier" switches on Type 2110.
    The absolute voltage level at any frequency in the recorded spectrogram is found by adding the number of db indicated by the position of the "Meter Range" and the "Range Multiplier" switches to the number of db read off the spectrogram at the frequency in question. *The sum gives the voltage level in db re. o.1 Volt.*
    Example:
    From a particular spectrogram the recorded level at 100 c/s was 30 db. The position of the "Meter Range" switch was "0 db (10 V)" and the "Range Multiplier" switch was set to "—10 db (x o.3)".
    The actual voltage level of the 100 c/s signal is then:
    0 db — 10 db + 30 db = 20 db re. o.1 Volt = 1 Volt.

Automatic Recording of Sound Spectrograms.

One of the most important features of the combination Spectrometer and Level Recorder is its ability, with the aid of one of the B & K Condenser Microphones, to record sound spectrograms automatically.

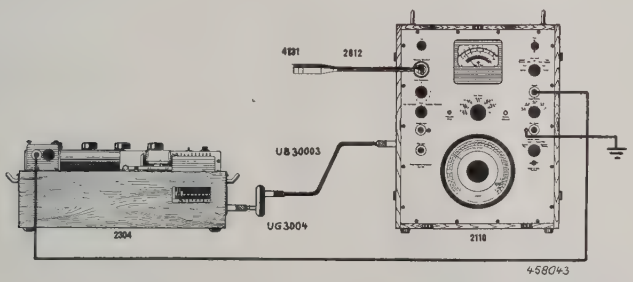


Fig. 15. Measuring arrangement for automatic recording of sound spectrograms.

Some typical examples of this type of measurements are given under "Application". The calibration and measuring procedures are the following: Connect the instrument as shown in fig. 15, and set the control knobs on the Spectrometer according to the following scheme:

1. Check the microphone polarization voltage (see page 13).
2. "Input Potentiometer": Any position.
3. "Input Switch": "Condenser Microphone".
4. "Meter Range": "1 V (100 db S.L.)".
5. "Filter Switch": "40" (c/s).
6. "Power": "On".
7. "Meter Switch": "Standard Damping, RMS".
8. "Range Multiplier": "x 0.3 (—10 db)".
9. "Function Selector": "Linear".

   Supply the Level Recorder with the desired type of preprinted recording paper and set the control knobs as follows (fig. 12):
10. "Zero Level Adjustment": Fully counter clockwise.
11. "Lower Lim. Frequency": "20 c/s".
12. "Potentiometer db Range": "50".
13. "Writing Speed": "140".
14. "Motor": "Off".
15. "Amplifier": "On".
16. "Slider": "Record".

    Place the Noise Source Type 4240 on the Condenser Microphone as shown in fig. 16. The black line on Type 4240 should be in a vertical position, and the Noise Source should be mounted on the Microphone in such a way that the text is read, as normal, from left to right, see also the instruction manual for this instrument. The sound level produced by the Source, when mounted as described above, is indicated on Type 4240 itself.

    Note: The Microphone should be kept in an exactly horizontal position!
17. Turn the plastic ring on the Source 180°. Both the Spectrometer meter and the Level Recorder stylus will now deflect.
18. Turn the Level Recorder "Input Potentiometer Knob" until the deflection

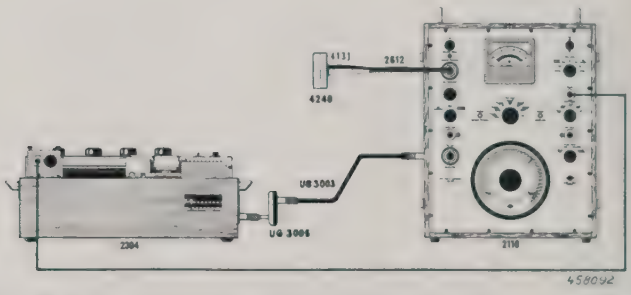


Fig. 16. Calibration of the measuring arrangement by means of Noise Source Type 4240.

of the stylus on the recording paper equals the number of db stated on the Noise Source housing —70 db.

19. Remove the Noise Source from the Microphone.
Remarks: The above calibration procedure is based on the use of a 50 db input potentiometer on the Level Recorder.
It is recommended, whenever sound measurements are carried out, to use this potentiometer, although other input potentiometers are available.

The actual measurements can now begin:

20. Expose the Microphone to the sound field and proceed as outlined under "Automatic Recording of Voltage Analyses" items 20 through 32, and note down the positions of the "Meter Range" and "Range Multiplier" switches.

Evaluation of Sound Spectrograms.

When the recorded spectrogram is evaluated the following definitions should be born in mind:

The Sound Pressure Level (S.P.L.) is expressed in db above a certain reference pressure (p_0) which is normally taken to be 2×10^{-4} μbar (dyne/cm^2), i.e. S.P.L. $= 20 \log p/p_0$. The S.P.L. value is obtained when the instruments used for the measurements have a linear frequency response to all audio frequencies. This definition and unit is used to express the overall physical sound pressure of any sound.

The S.P.L. value is recorded on the Level Recorder when the filter switch on the Spectrometer is in position "Lin. C", see fig. 17.

The ⅓ Octave S.P.L. is the sound pressure level within a ⅓ octave frequency band only. The center frequency of the band should always be stated. The ⅓ octave S.P.L. value is used in the evaluation procedure of a sound spectrogram, and is recorded on the Level Recorder when the Spectrometer filter switch is in any of the positions from "40" to "31 500". (When the Spectrometer is used with Extension Filter Type 1619 (ZS 0145) the ⅓ Octave S.P.L. value is obtained when the filter switch is in any position between "16" and "31 500"). See fig. 17.

The Sound Level is measured (recorded) with an instrumentation built to meet the standard specifications for sound level meters.

The Sound Level value describes, as closely as possible, by means of a single figure the strength of the sound as perceived by the human ear, see also "Appendix", p. 68.

Sound Levels were previously stated in "phons", but according to the latest international agreements the Sound Level, as here defined, should be expressed in db (db S.L.).

The Sound Level is recorded when the filter switch on the Spectrometer is in one of the positions "DIN 3", "DIN 2-A", "DIN 3-B" or "Lin-C". See also fig. 17.

When the measuring arrangement is calibrated as described under "Automatic Recording of Sound Spectrograms", p. 19, the above defined levels can all be found from the recorded spectrogram as follows:

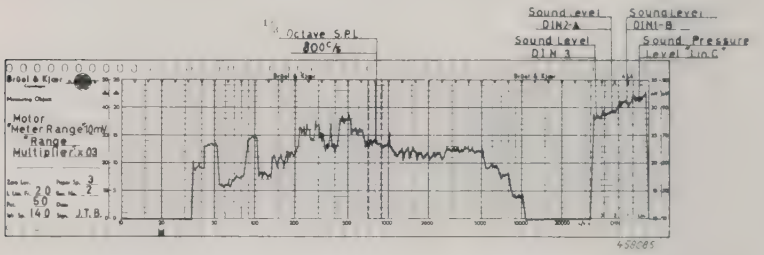


Fig. 17. Example of recorded spectrogram with indication of the Sound Pressure Level, the ⅓ Octave S.P.L. and the Sound Level.

Add the number of db read off the spectrogram to the db S.L. values, indicated by the position of the "Meter Range" and "Range Multiplier" switches on the Spectrometer. The actual levels are now found by subtracting 20 db from this figure, i.e.:

Sound Pressure Level
⅓ Octave S.P.L.
Sound Level
in db re. 2×10^{-4} μbar.

$=$ db on spectrogram + db S.L. on "Meter Range" switch + db on "Range Multiplier" switch — 20 db.

Note: The actual Sound Level value, which is one single figure, is found considering that the calculated Sound Level must lie within the limits stated below:

Weighting Network inserted	Sound Level Limits
DIN 3	0— 30 (db)
DIN 2 - A	30 — 60 (db)
DIN 1 - B	60 — 130 (db)
Lin. - C	130 (db)

An example will illustrate this:

If the Sound Level recorded with the Spectrometer filter switch in position "DIN 3" is 68 db, the Sound Level value recorded with the filter switch in position "DIN 2 - A" is 70 db, the Sound Level recorded with the switch in

position "DIN 3 - B" is 73 db, only the Sound Level value 73 db is correct because it lies within the limits "60—130". In case the recorded Sound Level is higher than 130 db the value found when the Spectrometer filter switch is in position "Lin. - C" will be the correct Sound Level.

Recording of the Sound Level as a Function of Time.

The measuring arrangement used when it is desired to record the Sound Level continuously as a function of time is the same as the one shown in fig. 15. The following procedure should be applied:

1. Record a spectrogram of the sound as described under "Automatic Recording of Sound Spectrograms".
2. Evaluate the correct actual Sound Level from the recorded spectrogram as described under "Evaluation of Sound Spectrograms".
3. Replace the paper on the Level Recorder by Type QP 2350, QP 2351 or QP 2352.
4. Set the switch marked "Function Selector" on the Spectrometer to position "Internal Filter".
5. Turn the filter switch on the Spectrometer to its correct position with regard to the sound level being measured ("DIN 1", "DIN 2-A", "DIN 3-B" or "LIN. C"), and keep the setting of all other control knobs unchanged.
6. Determine the desired paper speed and engage the corresponding lever on the Level Recorder gearbox.
7. Start the Level Recorder motor.
   When the desired period of time for the recording has passed, the Level Recorder motor is stopped and the paper cut off for evaluation.

Calibration of the Combination Spectrometer and Condenser Microphone for Sound Surveys.

In some cases it is desired only to measure the sound pressure level, or the sound level, directly on the Spectrometer meter. The combination Spectrometer + Condenser Microphone may then be calibrated in the following way:

1. The Spectrometer "Input Potentiometer" can be in any position.
2. "Input Switch": "Condenser Microphone".
3. "Meter Range": "Ref.".
4. "Filter Switch": Any position.
5. "Power": "On".
6. "Meter Switch": "Standard Damping RMS".
7. "Range Multiplier": "x 1 (0 db)".
8. "Function Selector": "Linear".
9. Allow two minutes warm-up time.
10. From the calibration curve of the Microphone employed a correction factor "K" in db is found, see also fig. 18.

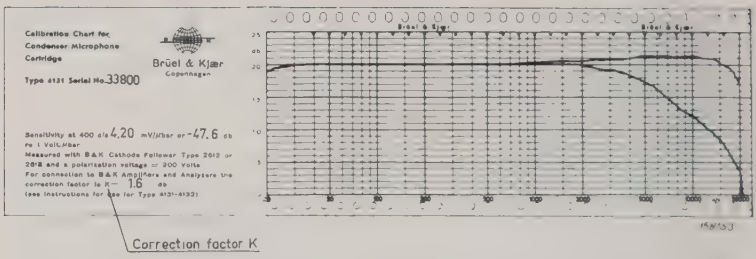


Fig. 18. Typical Microphone calibration curve with indication of the correction factor "K".

11. Turn the "Sensitivity-Condenser Microphone" potentiometer by means of a screwdriver until the meter pointer deflects to (10 + "K") db.
12. The Condenser Microphone should now be exposed to the sound field, and the "Meter Range" switch turned counter clockwise until a suitable deflection is obtained on the instrument meter. If a convenient deflection on the meter cannot be obtained by using the "Meter Range" switch only, the "Range Multiplier" switch may be set to position "x 0.3 (—10 db)".
13. Set "Function Selector" to "Internal Filter".
14. The sound pressure level (or sound level, depending upon the position of the Spectrometer filter switch) can now be read off the instrument meter

S.L.
S.P.L.
in db re. 2×10^{-4} µbar. = db on instrument meter + db S.L. on "Meter Range" switch + db on "Range Multiplier" switch.

If desired, the calibration can be checked by means of the Noise Source Type 4240.

Combined Units and Auxiliary Equipment.

The Audio Frequency Spectrum Recorder Type 3310.

The Audio Frequency Spectrum Recorder consists of the Spectrometer Type 2110 and the Level Recorder Type 2304 mounted together in a 19" rack.

The filter switch of the Spectrometer is mechanically connected to the motor in the Level Recorder by means of a chain drive.

This arrangement makes it possible to record spectrograms automatically on preprinted, frequency calibrated recording paper without use of the the Speed Multiplier UG 3004, because the proper speed convertion is taken care of by the chain drive itself.

The operation of the unit is the same as described under "Operation" p. 14 through p. 24.

Fig. 19 shows a drawing of Type 3310.

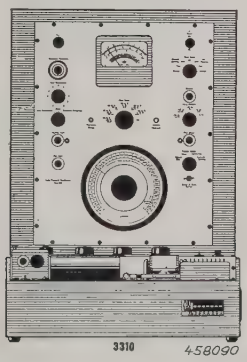


Fig. 19. Drawing of Type 3310.

The A. F. Response and Spectrum Recorder, Type 3320.

Following up the line of Combined Units for automatic measurements, a further Unit namely the A. F. Response and Spectrum Recorder Type 3320 has been designed.

It is a combination of the Beat Frequency Oscillator, Type 1014, the Audio Frequency Spectrometer, Type 2110, and the Level Recorder, Type 2304, all mechanically coupled together.

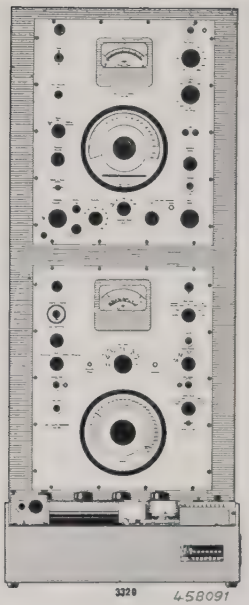


Fig. 20. Drawing of Type 3320.

With the aid of these instruments almost any desired, electrical, electro-acoustical or acoustical measurement in the audio frequency range can be carried out and recorded.

Fig. 20 shows a drawing of the Apparatus.

The instruments can be used separately or together in various combinations. An interesting application of the Type 3320 is selective measurements of the frequency characteristic of four-terminal networks, which can be carried out automatically. This is of special importance when the four terminal network is an electro-acoustical system where the noise level might be too high to obtain reliable non-selective measurements.

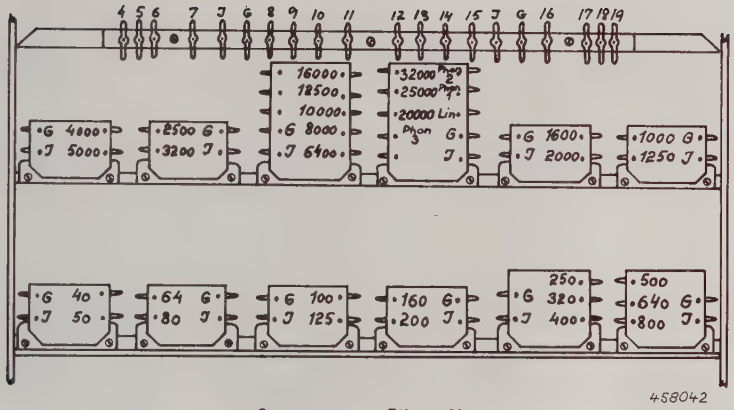
Further information concerning the A. F. Response and Spectrum Recorder is given in the instruction manual for the Beat Frequency Oscillator Type 1014.

Extension Filters.

External filters may be used in connection with the built-in amplifiers in the Spectrometer Type 2110 when special precautions are taken.

However, a "Standard" filter set is available on request extending the

Note: The DC voltage across the "Filter Input" terminals is approx. 75 volts.



Spectrometer Filter Chassis

Fig. 21. Drawing of the filter chassis in Type 2110 with terminal board (viewed from the back).

normal measuring range of the Spectrometer to frequencies down to 16 c/s (filter center frequency).

The Set is built up in "drawers" and mounted on a chassis. It is available either in a mahogany case (Extension Filter Set Type 1619) or as separate chassis only (ZS 0145).

The Extension Filter Set Type 1619 can be connected to the Spectrometer terminal "Filter Input - Extension Filter" by means of a seven poled screened cable. The adaptor, which is normally mounted in the "Filter Input - Extension Filter" terminal of the Spectrometer should then be removed and the seven poled plug of the connection cable connected instead.

In case the Extension Filter Set should be used in connection with the Spectrum Recorder Type 3310 or the A. F. Response and Spectrum Recorder Type 3320 it is possible to mount the Set in Type 3310 (or Type 3320) itself. The mahogany case is then superfluous and the Set is delivered on the chassis only. Connection of the filters to the Spectrometer filter switch can be made internally as follows, see also fig. 21:

black	wire from ZS 0145	— to point	J	on filter chassis 2110
red	wire from ZS 0145	— to point	G	on filter chassis 2110
green	wire from ZS 0145	— to point	16	on filter chassis 2110
blue	wire from ZS 0145	— to point	17	on filter chassis 2110
brown	wire from ZS 0145	— to point	18	on filter chassis 2110
yellow	wire from ZS 0145	— to point	19	on filter chassis 2110

Note: When the filters ZS 0145 are connected as indicated above, the connections a, b, c, d, e and f to the socket "Filter Input - Extension Filter" must be removed, see also fig. 22.

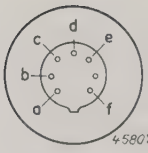


Fig. 22. Socket "Filter Input - - Extension Filter" viewed from the back.

Fig. 23a. Drawing of Type 1619.

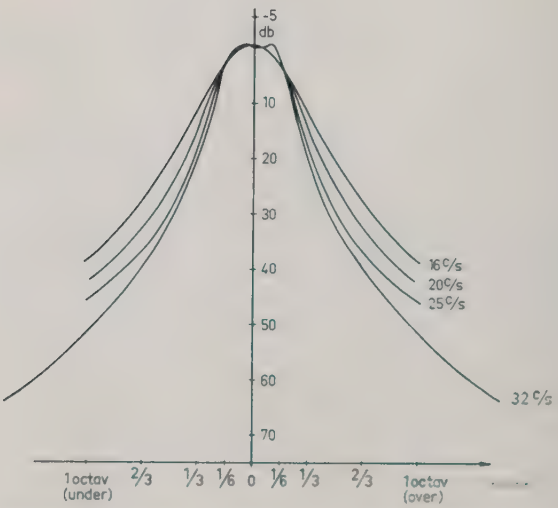


Fig. 23b. Typeical filter characteristics for the filters contained in Type 1619.

Fig. 23 shows a drawing of Type 1619 and some typical frequency characteristics of the filters.

Recording Paper.

Different types of pre-printed recording paper to be used on the Level Recorder, Type 2304 in conjunction with other instruments such as the Spectrometer or the Beat Frequency Oscillator are available.

The paper can be supplied in several qualities such as white paper for ink writing, white-waxed black paper for use with a sapphire stylus and red-waxed, transparent paper, also for use with the sapphire stylus.

The red-waxed transparent paper is specially made for blue prints. However, the scales on the pre-printed paper are made in black, and will thus not be copied when blue prints or photostatic copies are made. Only the measured curve will then appear on the copy. Fig. 24 shows the frequency calibrated papers which should be applied when measurements are taken with the Spectrometer and recorded on the Level Recorder.

To obtain the calibrated scales together with the measured curve on the copy, it is necessary to employ a Photographic Negative, and carry out a "double copying".

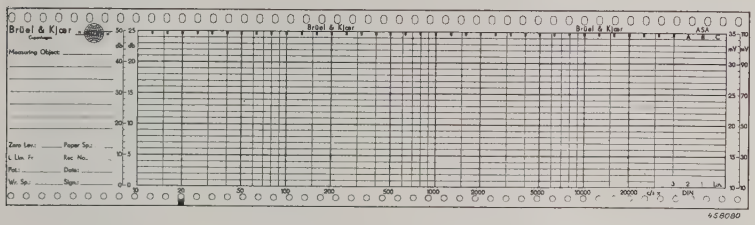


Fig. 24. Example of the preprinted, frequency calibrated recording paper to be used when spectrograms are recorded on the Level Recorder Type 2304.

The Photographic Negative is a black film on which the scales appear as transparent lines, see fig. 25.

The following procedure can now be applied for the "double copying":

The recorded paper strip is fastened to a board (or table) with Scotch Tape, such that the whole strip can be turned to one side and a piece of copying

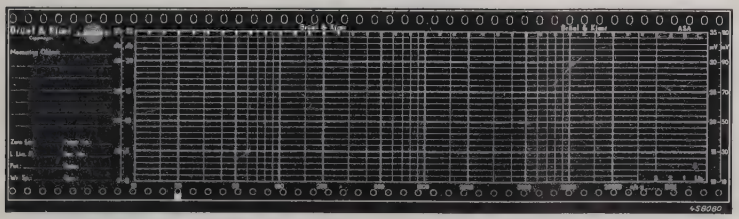


Fig. 25. The Photographic Negative QF 0003 with transparent frequency-amplitude scales.

paper inserted underneath, without shifting the position of the strip. The Photographic Negative is then placed on the recorded paper strip, the printing on the strip coinciding precisely with the transparent lines on the film. By using Scotch Tape the film is fixed to the board. Care should be taken, that also the film can be turned to one side.

The photostat paper is now placed underneath the recording paper strip only and the curve illuminated. Then, without disturbing the photostat paper, the recorded paper strip is turned to the side, the black film in turn laid on the photostat paper, and the frequency diagram copied. By illuminating the curve somewhat longer than the black film with the frequency diagram, it is possible to enhance the former whereby it will stand out in contrast to the lines in the latter.

The Two Channel Microphone Selector Type 4408.

This apparatus is designed as an accessory to the Analyzers and Microphone Amplifiers produced by Brüel & Kjær.

The output from one or the other of two Condenser Microphones can be automatically or manually switched into a single amplifier.

A recording of two phenomena, e.g. the sound pressure at two different points in a sound field, can thus be obtained on a Level Recorder.

A typical application of the Two Channel Microphone Selector is given on p. 56, "Production Line Testing of Domestic Apparatus with Regard to Noise". The Microphone Selector is built in a metal box as shown in fig. 26, and contains a toggle switch which operates a relay, and the components necessary for the elimination of hum and crosstalk effects.

Fig. 26. The Two Channel Microphone Selector Type 4408.

When the Selector Type 4408 is operated manually the toggle switch is employed. The switch then operates the relay, which in turn switches the output from 4408 to one or the other of its two inputs.

The Selector, Type 4408 may also be remote controlled. The toggle switch must then be in position "2", and the external control switch by means of a cable connected to the terminals marked "External Control", whereby the external switch replaces the function of the toggle switch.

Some technical data:

The Two Channel Microphone Selector is designed especially for use with the B. & K. Condenser Microphones.

The cross-talk effect is negligible. Due to coupling in the H. T.-supply (between the two anodes) the effect of crosstalk is greatest at lower frequencies, but is reduced by more than 80 db at 20 c/s.

Transients in the switching-over from one input to the other may last for approx. 100 msec.

NB! Due to the series heating of the tubes the Type 4408 can only be used when both Microphones are connected.

The 1/3 Octave Filter Set Type 1610.

The instrument contains the same 30 one third-octave filters and weighting networks as the Spectrometer, but the filters are built in a special wooden case as shown in fig. 27. When used together with the Microphone Amplifier Type 2603 this combination is equivalent to a complete Spectrometer, having a greater flexibility at the expence of larger volume and greater weight. A drawing of 2603 + 1610 is shown in fig. 28.

Fig. 27. The 1/3 Octave Filter Set Type 1610.

The Filter Set itself can also be used separately when properly matched.

Proper matching requires a source impedance of approx. 10 Ω and a load impedance of approx. 152 kΩ.

However, to enable the Filter Set to be used also in connection with equipment which does not fulfill these requirements a built-in transformer with the transformation ratio 10 : 1 can be switched in between the input terminal of the instrument and the filter input circuit. Source impedances up to 2500 Ω may then be connected to the Filter Set without disturbing the shape of the filter curves severely. The recommended relationship between source and load impedance, when correct matching conditions can not be obtained, is given in fig. 29.

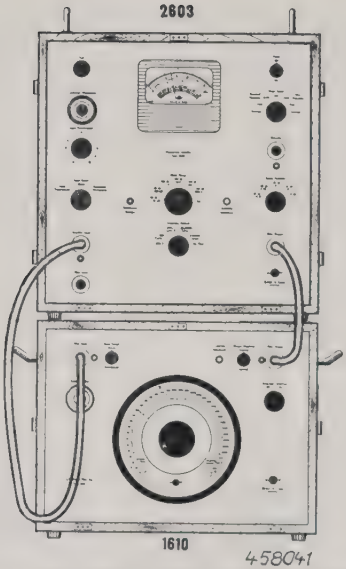


Fig. 28. Connection of Type 1610 to Microphone Amplifier Type 2603. This combination is equivalent to a complete Spectrometer 2110.

When Type 1610 is connected to the Microphone Amplifier Type 2603 the switch marked "Output Matching" should be in position "Internal", whereby a resistor of 170 kΩ is connected across the filter output circuit. This resistor in combination with the Microphone Amplifier input impedance then ensures correct load condtions for the filters.

The maximum permissible input voltage to the Filter Set is 10 volts when the input transformer is switched in, and 1 volt if the voltage is applied directly to the filters. Accordingly the transmission loss in the passband is 20 db with transformer and 0 db without transformer.

At lower frequencies, however, the maximum input voltage should be smaller than the above mentioned 10 volts due to distortion in the input transformer, see fig. 30. For frequencies below 20 c/s the curve indicates the 1 % distortion level.

The Filter Set Type 1610 is, similar to Type 2110, also supplied with a seven-poled socket which enables the connection of the Extension Filter Set Type 1619.

A trimmer capacitor of 60 pF is paralleling the output terminals of Type 1610. This capacitor is accessible through a hole in the front panel of the

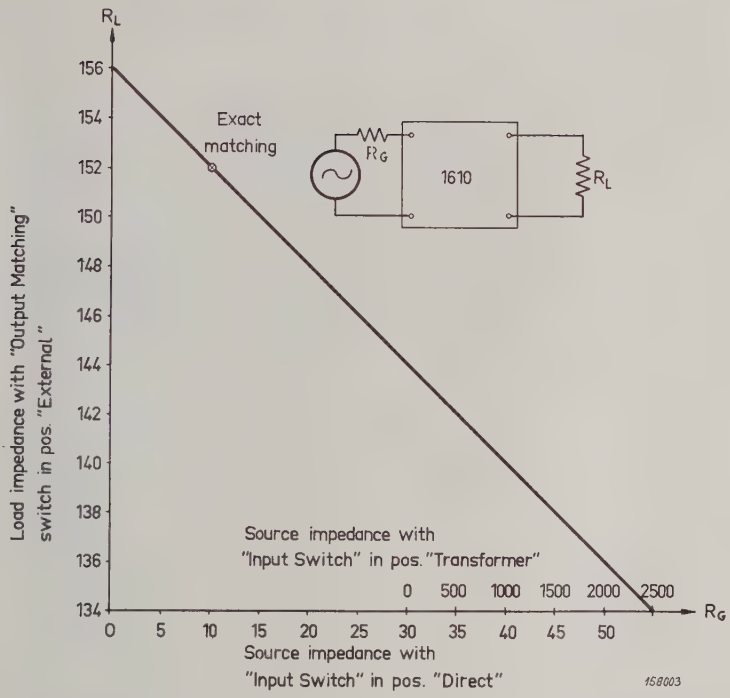


Fig. 29. Recommended relationship between source and load impedance for the ⅓ Octave Filter Set Type 1610.

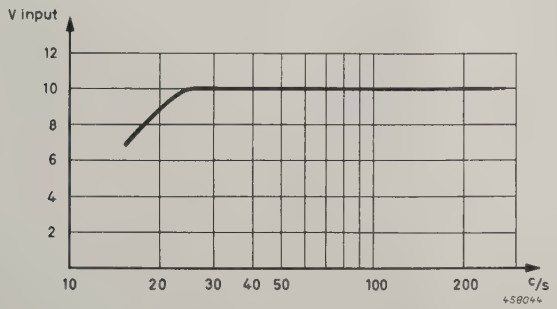


Fig. 30. Maximum input voltage to be applied to Type 1610 when the input transformer is switched in (1 % distortion limit).

instrument marked "Capacity Adjustment", and should be tuned to ensure symmetrical filter characteristics at the high frequency end of the total frequency range.

The Filter Set can be mechanically coupled to the Level Recorder Type 2304 by means of the Flexible Shaft UB 3003 and Speed Multiplier UG 3004. A switch on the front panel marked "Automatic Switching" enables, when in position "On", the automatic recording of spectrograms in the same way as mentioned under "Operation" p. 14 through p. 24.

Note: Use low-capacity cables when Type 1610 is connected to other equipment. A special low capacity cable is supplied with the instrument when it is delivered from the factory. This cable should be used for connecting the output of Type 1610 to the Microphone Amplifier Type 2603 when this combination of instruments is used.

Applications.

Distortion Measurements.

The non-linear distortion in four-terminal networks is normally expressed by means of the formula:

$$d = 100 \sqrt{\frac{A_2^2 + A_3^2 + A_4^2 + \ldots}{A_1^2 + A_2^2 + A_3^2 + \ldots}} \sim 100 \frac{\sqrt{A_2^2 + A_3^2 + A_4^2 + \ldots}}{A_1} \quad \%$$

The factor d can be measured directly in a single measurement when the Spectrometer Type 2110 is used in connection with the frequency and Distortion Measuring Bridge Type 1602, see fig. 31.

Type 1602 is basically a variable blocking network, by means of which any frequency in the range 47 c/s to 12000 c/s can be attenuated by more than 80 db while all other frequencies are allowed to pass the network without attenuation.

To measure the factor d the complete signal should first be fed to Type 2110, and the meter pointer of the instrument adjusted to give max. deflection. The measuring frequency is then blocked out by means of Type 1602, and the reading on the Spectrometer meter is now the factor d %. *Note:* The Spectrometer must be switched to measure the R.M.S. value of the signal.

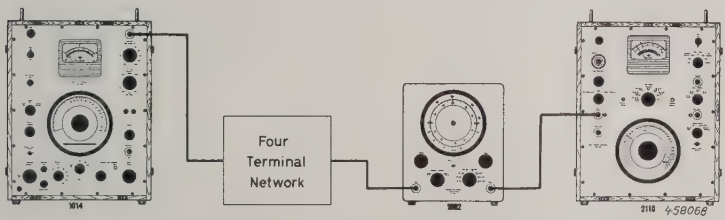


Fig. 31. Measuring arrangement suitable for distortion measurements.

In the above mentioned measuring set-up the Beat Frequency Oscillator Type 1014 is used as signal source. The Oscillator itself has a distortion factor of 0.25 % at 1000 c/s when loaded with 1 watt, and will thus be well suited for normal distortion measurements where the factor d of the network being tested is greater than 3 %. However, in high fidelity audio frequency amplifiers, and other equipment with extreme low distortion the measuring arrangement shown in fig. 31 should be substituted with the one shown in fig. 32a.

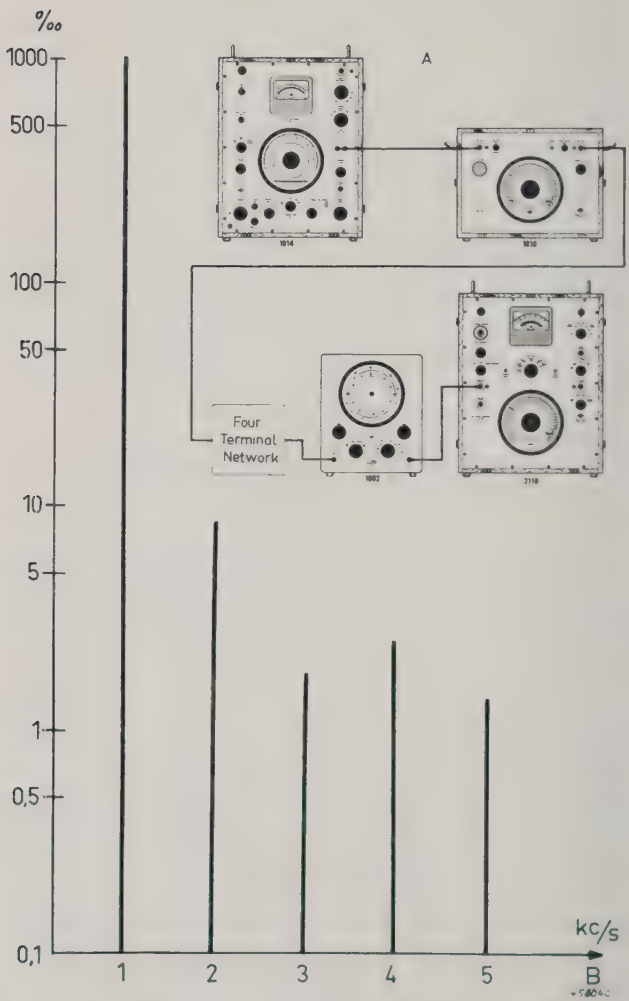


Fig. 32. Distortion measurements on networks with extremely small harmonic distortion:

a. Measuring set-up.

b. Frequency spectrum of an analyzed signal.

The Filter Set Type 1610 will attenuate the harmonics of the Oscillator output signal by more than 50 db and it is then possible to measure harmonic distortions as low as 10^{-2} %.

When desired the signal being measured can also be analyzed, see fig. 32b.

The Audio Frequency Spectrometer used as Bridge Indicator.

When bridge measurements are carried out in the audio frequency range it is a great advantage to have a selective instrument in the bridge network because the disturbing noise level is proportional to the square-root of the instrument band-width. The only requirement the bridge itself must satisfy is that one diagonal point can be grounded as shown in fig. 33. This requires the bridge to be supplied from an oscillator via a screened transformer, the signal generator often being grounded at one terminal.

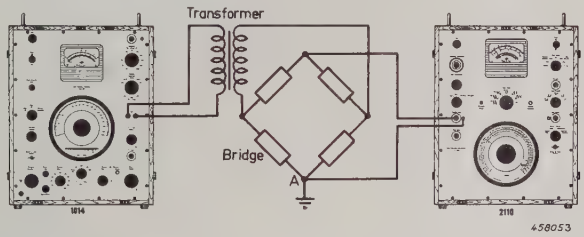


Fig. 33. The Spectrometer used as bridge indicator.

Due to the selectivity and great sensitivity of the Spectrometer it is well suited for bridge measurements. Furthermore, by employing the Spectrometer as measuring instrument in a bridge measuring arrangement it is possible to vary the oscillator frequency to some extent (⅓ octave) without changing the setting on the Spectrometer.

Vibration Measurements and Analyses.

Using the Accelerometer Sets Type 4308 or 4309 and the Vibration Pick-up Preamplifier Type 1606 or Cathode Follower Type 2612 or 2613 with Adaptor JJ 2612 vibrations in buildings, machinery, ships etc. can be measured directly.

The Accelerometers employ piezo-electric ceramic as mechanical-electrical transducing material and the Type 4308 has a sensitivity of approx. 30 mV per 1000 cm sec.$^{-2}$. The frequency response is flat from 5 c/s to approx. 20 kc/s, the first (principal) resonance occuring at 25—35 kc/s. Type 4309 has a sensitivity of approx. 10 mV per 1ooo cm/sec^{-2} and the principal resonance occurs at 40—50 kc/s.

The Vibration Pick-up Preamplifier Type 1606 consists basically of an amplifier with very high input impedance ($>$ 50 Mohms), and the integrating networks necessary to convert the output voltage from an accelerometer to

a voltage proportional to the velocity or displacement level of the vibrations, respectively. It contains, furthermore, a small shaker table for absolute calibration of the measuring arrangement.

When it is desired to measure the velocity level of the vibrations considered the Preamplifier should be switched to "Velocity cm/sec.". The output from the Accelerometer is then integrated once with respect to time and the output from the Preamplifier is proportional to the vibration velocity level. To obtain the velocity level in cm/sec. it is only necessary to read the output voltage in mV on the Spectrometer and multiply by the conversion factor indicated on the Preamplifier. The velocity-amplitude is then immediately given in cm/sec. In position deflection-amplitudes a further integration is carried out. With each integration a certain degree of accuracy is lost, and it is therefore recommended to work mainly with acceleration and velocity amplitudes, and that deflection-amplitudes be only seldom used. In any case there is seldom use for deflection-amplitudes, as the forces to which various objects are subjected are directly proportional to the acceleration, and the "irritation effects" which vibrations have on people are in the main proportional to the velocity-amplitudes.

Fig. 34 shows a typical example of a set-up employing Vibration Pick-up 4308, Preamplifier 1606 and Spectrometer 2110 for the measurement of vibrations of an automobile engine, together with the measured result.

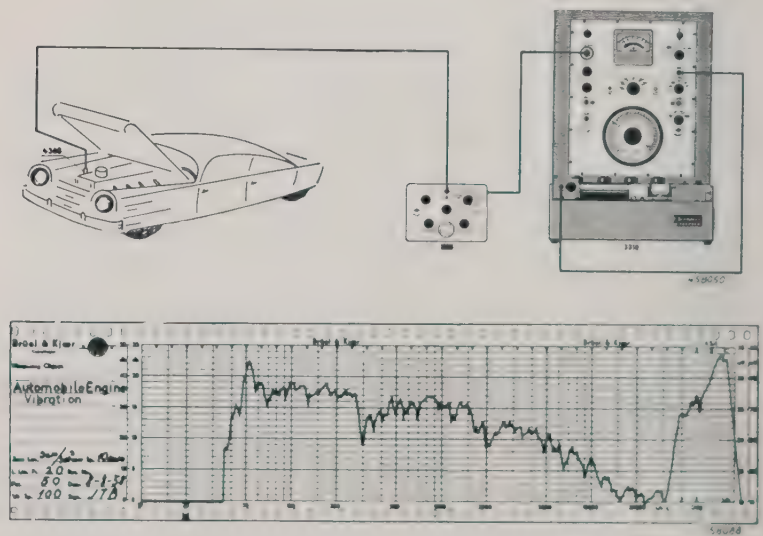


Fig. 34. Vibration measurement on an automobile engine.

Fig. 35 shows the measurement of vibrations in a motor foundation. Below the figure are the results of measurements on the foundation itself at the position marked A on the figure, and measurements at the same frequencies, but at a point marked B outside the vibration-isolated foundation.

Measurement of Typewriter Noise.

The noise produced by typewriters in modern offices is many times a very serious problem because it annoys other people working in the office or offices in the immediate vicinity of where the typewriter is placed, and reduces the efficiency of their work. This problem is even greater when more typewriters are placed in the same room. Great efforts have therefore been spent during recent years to make noiseless typewriters. The combination of the Spectrometer and Condenser Microphone constitutes a very convenient unit for the measurement of typewriter noise, because this instrumentation

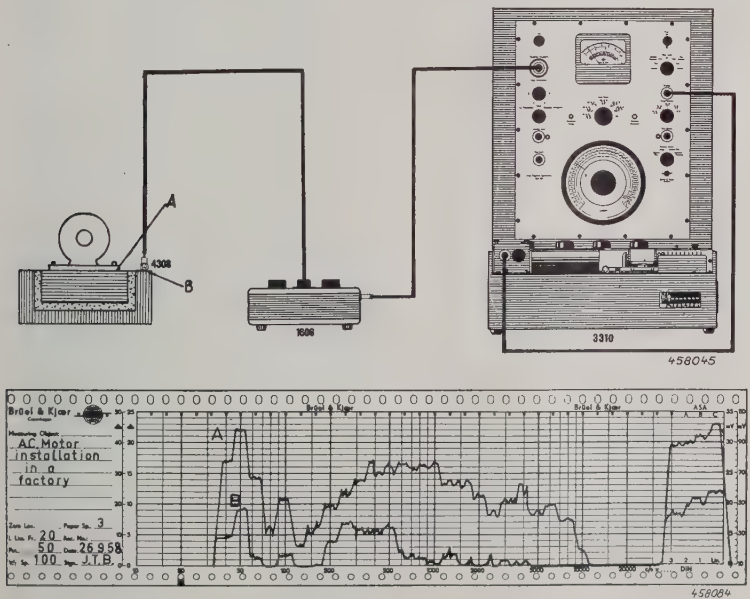


Fig. 35. Vibration insulation measurements. The measurements are recorded automatically on the Level Recorder of Type 3310.

makes it possible to measure not only the *arithmetic average value of the radiated noise, but also its r.m.s. and "peak" value.* The character of the noise as well as its "annoying" effects can then be much better judged than

it can from ordinary measurements of the arithmetic average value. Fig. 37 shows a spectrogram taken of the noise produced by an electric typewriter with a distance of approx. 0.5 m between the microphone and the typewriter. For the sake of convenience the results of the measurement are plotted on the same type of paper that is normally used for automatic recording of spectrograms.

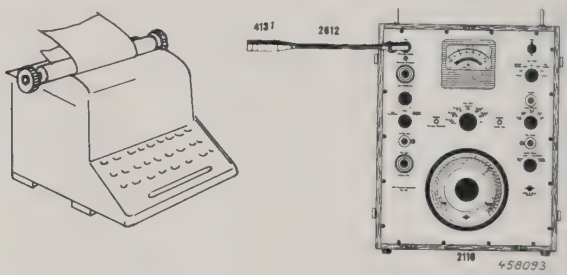


Fig. 36. Measurement of typewriter noise.

It can be seen from the spectrogram that the difference between the peak, r.m.s., and the arithmetic average value of the noise depends, to a certain extent, upon frequency, which is also to be expected from the character of the

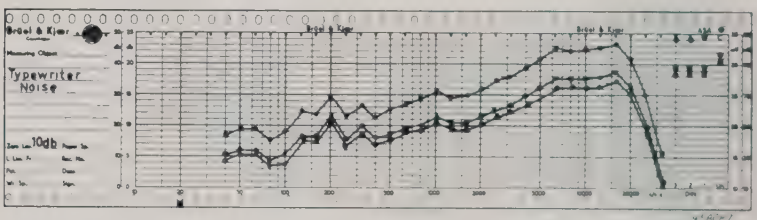


Fig. 37. Spectrogram of the noise produced by a typewriter.

noise. It should, however, be noted that the peak values given in the figure are not the actual peak values but rather an average of "half the peak to peak"-value.

Spectrograms.

The most important application of the Audio Frequency Spectrometer is the automatic recording of sound Spectrograms, see also "Operation" p. 14 through p. 24.

Some typical spectrograms measured by means of the set-up of fig. 38 are shown in the following.

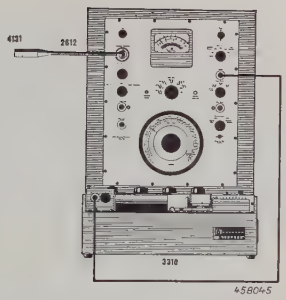


Fig. 38. Measuring arrangement for the recording of sound spectrograms.

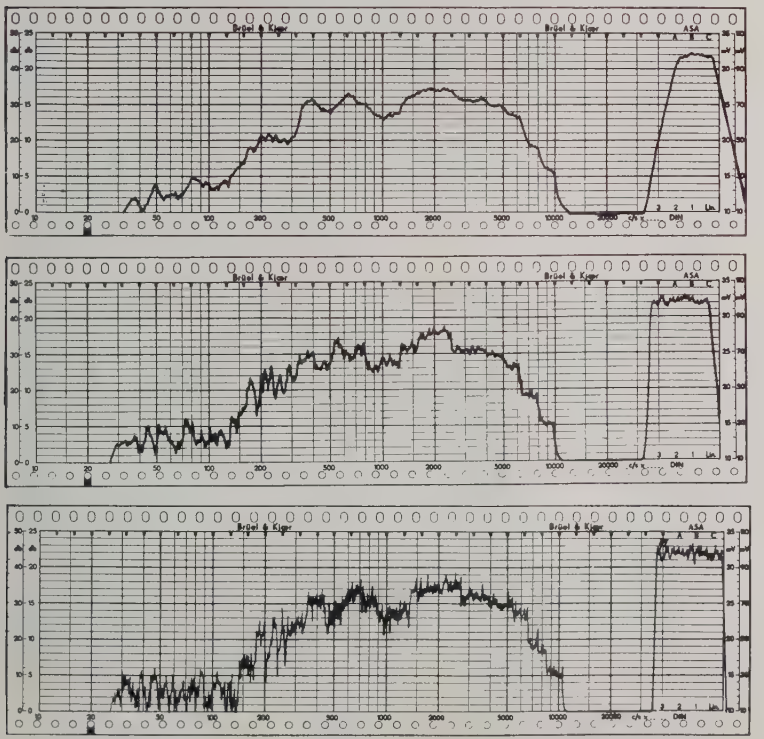


Fig. 39. Spectrograms of the noise from a lathe, taken with three different writing speeds of the Level Recorder: 50, 200, and 700 db/sec. (A 50 db potentiometer was used). Zero level: 2×10^{-2} μbar.

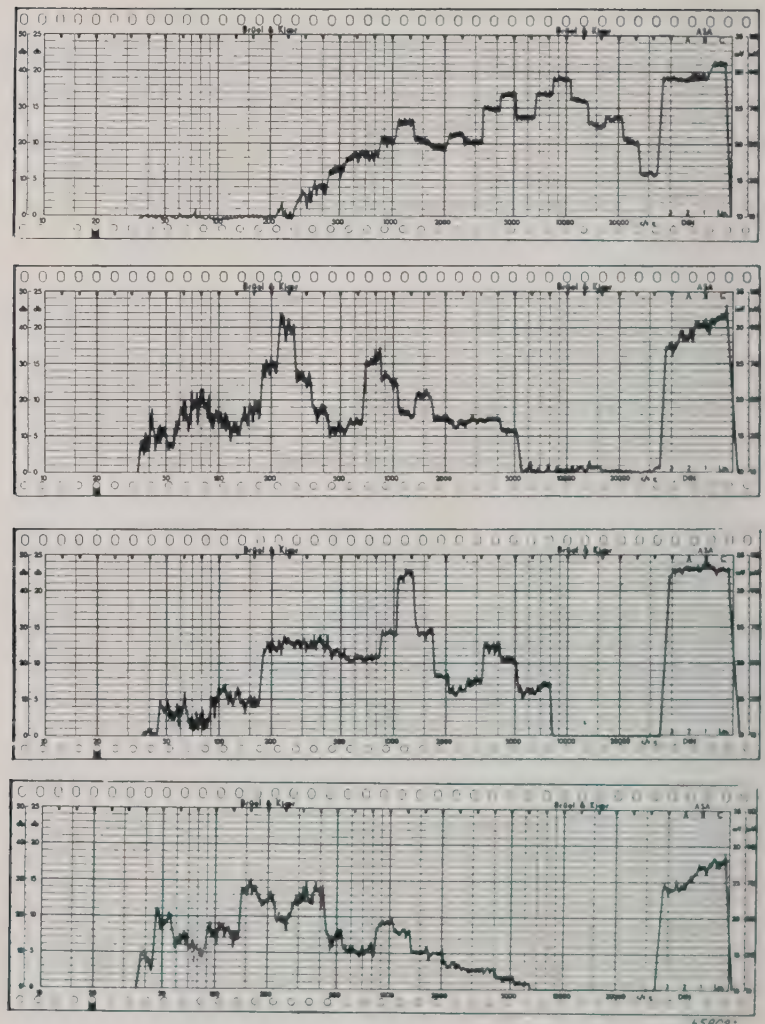


Fig. 40. Spectrogram of the sound from:

1. *Air streaming from pipes. Zero level: 6×10^{-2} μbar.*
2. *Electric motor on stamping machine. Zero level: 10^{-2} μbar.*
3. *Motor for small drilling machine. Zero level: 10^{-2} μbar.*
4. *Motor for large drilling machine. Zero level: 10^{-2} μbar.*

All recorded with 50 db potentiometer.

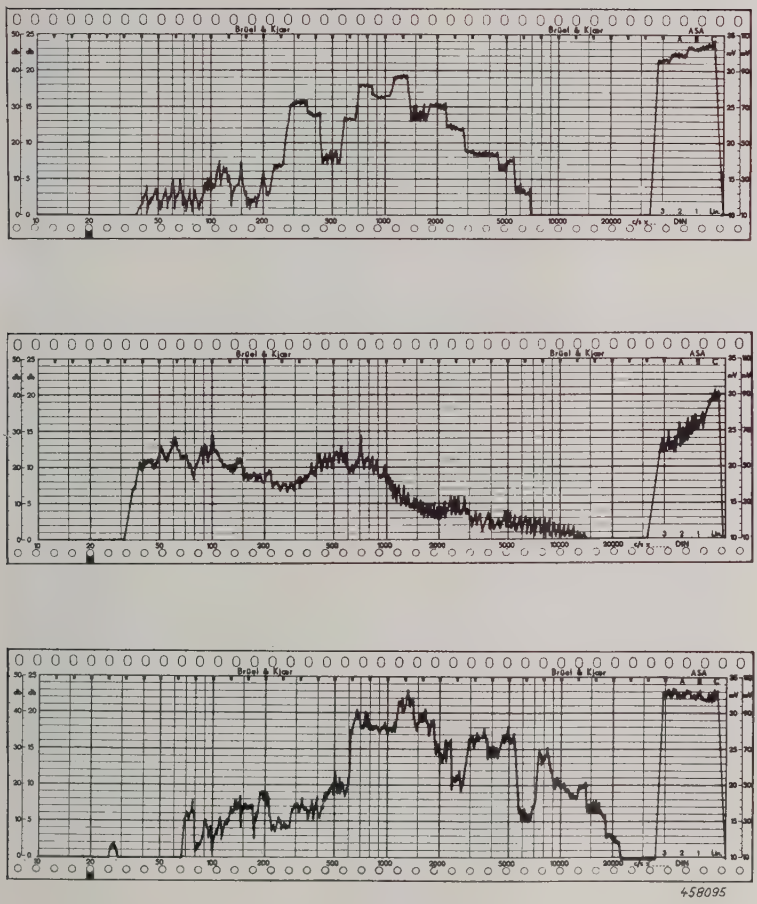


Fig. 41. Spectrogram of:
1. *Double toned automobile horn. Zero level: 1 μbar.*
2. *Watch P7R 12348. Distance 50 cms. Zero level: 6×10^{-4} μbar.*
3. *Alarm clock ringing. Zero level: 2×10^{-2} μbar.*

Fig. 39 shows the spectrogram of the noise radiated from a lathe. The three different curves are recorded with different writing speeds on the recorder. The curve is considerably smoothed out when low writing speed is employed on the Level Recorder.

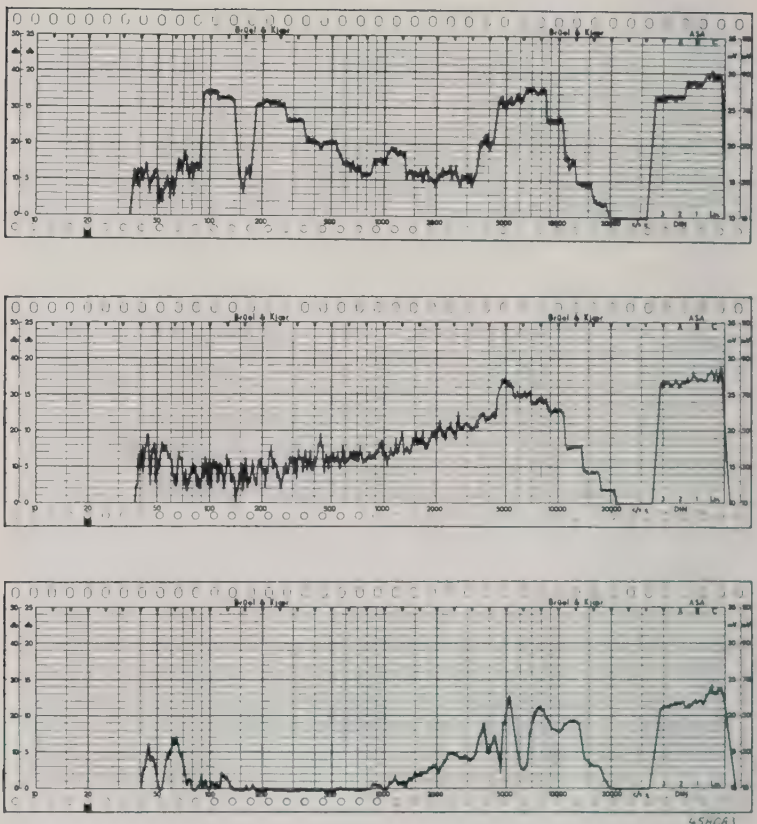


Fig. 42. Spectrogram of speech sounds:
1. a as in father.
2. Z as in zero.
3. S as in Mississippi.
Zero level 10^{-2} μbar.

However, with a high writing speed all the small variations in the sound level become quite pronounced. Note the fact that the irregularities in the sound level, when recorded with a linear characteristic, are considerably smaller than the irregularities of the separate bands. Furthermore, the irregularities in the separate bands are greater for the lower than for the higher frequencies, which are in agreement with the general statistical theory for the reflection of sound waves in enclosures.

Fig. 40 (top) shows a characteristic spectrum of the sound produced by air streaming out of a system of pipes. As can be seen from the figure this type of noise consists almost entirely of high frequencies.

The three following spectrograms are all taken from measurements on electric motors. In fig. 41 different "characteristic sounds" are analyzed. The reference levels are indicated in the figure.

In the middle is shown a spectrogram taken from measurements on an ordinary wrist-watch at a distance of approx. 20 inches. The Spectrum Recorder operates in this case just above its own noise level, i.e. about the lowest level at which measurements can be taken.

Fig. 42 shows some spectrograms obtained from measurements on speech sounds. The recordings are made with a paper-speed of 10 mm/sec., and consequently also a high writing speed had to be employed on the Level Recorder.

Measuring of Acoustic Noise from Small Objects.

Measurement of noise levels and the determination of acoustic spectrograms of noise from small objects like domestic apparatus, small electrical motors, fluorescent lamp mountings etc. is difficult, because the level of the noise to be measured is extremely low.

To increase the acoustic effect from the objects, and reduce external disturbances, it is recommended that the objects be placed in a special oblique-angled measuring box or a small measuring room with very hard, sound reflecting walls. A room with a volume V of about 2 m^3 and with walls, floor and ceiling constructed of 10 cm concrete, covered internally with smooth and hard tiles, is suitable. The reverberation time T can easily be brought up to about 2 sec, and with the help of small resonators be adjusted for constancy over a frequency range from 60—5000 c/s.

With a 2 sec reverberation time the total absorption in the measuring space is

$$\sum a\,S = A = \frac{0.16\,V}{T} = 0.16\ m^2$$

The intensity in the room is

$$E = \frac{4N}{c\,A}$$

where N is the total energy radiated from the test object, c is the velocity of sound. A point source of sound with the same radiation intensity placed in a sound-absorbing chamber will at a distance R give an intensity

$$E = \frac{N}{c\,4\pi R^2}$$

We thus find from the above example that the distance R_0 which gives the same sound level as in the sound reflecting measuring room is

$$R_0 = \sqrt{\frac{A}{16\pi}} = 0.06\ m$$

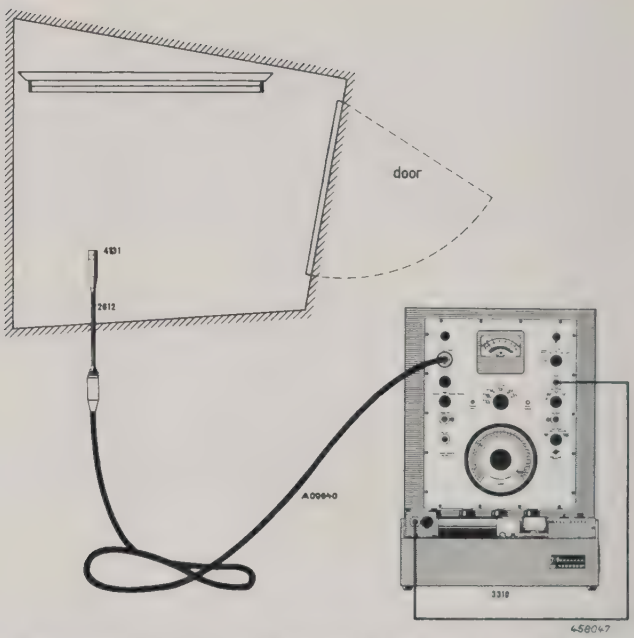


Fig. 43. Measurement of the noise produced by small objects like domestic equipment, fluorescent lamps etc.

As most test objects are of much greater dimensions than this distance, it is not possible to measure in a sound-absorbing chamber at such a small distance and have the various components of the noise represented. In order to measure in a sound absorbing chamber the measuring distance must be about 1 2 meters, which reduces the sound pressure being measured to 1/20.

Fig. 43 shows a sketch of a practical measuring room with oblique angles For sound measurements such a reflecting box the Condenser Microphone with Extension Cable AO 0040 (3 m) or AO 0041 (10 m) should be used.

Measurement of Reverberation Time.

One of the most important factors determining the acoustic properties of a room is its reverberation time. This time may be measured in different ways and two of the methods which can be employed will be discussed in the following.

It is possible to carry out the measurements by employing an Audio Frequency Spectrum Recorder Type 3310 together with a Condenser Microphone only.

In this case, however, the sound source must generate a sound which has the character of a white noise.

When only a limited number of reverberation curves are to be taken the shot from a gun might be used as sound source. Fig. 44 shows the measuring arrangement to be employed, together with some typical reverberation curves. Instead of the Spectrum Recorder Type 3310 use is here made of the Spectrometer and Level Recorder as separate instruments.

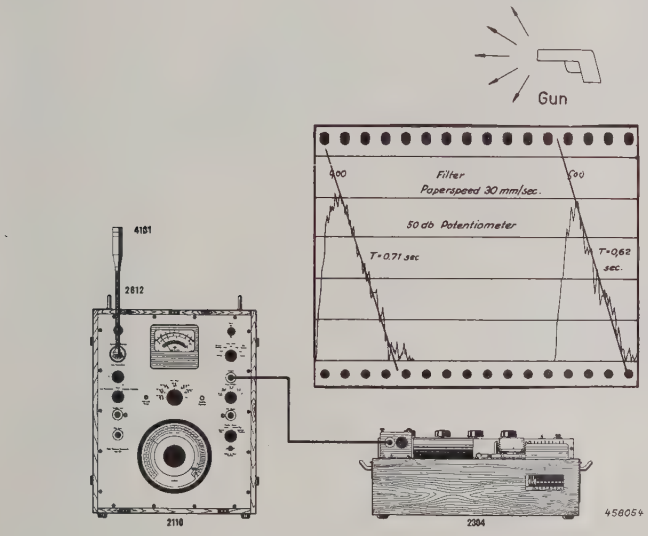


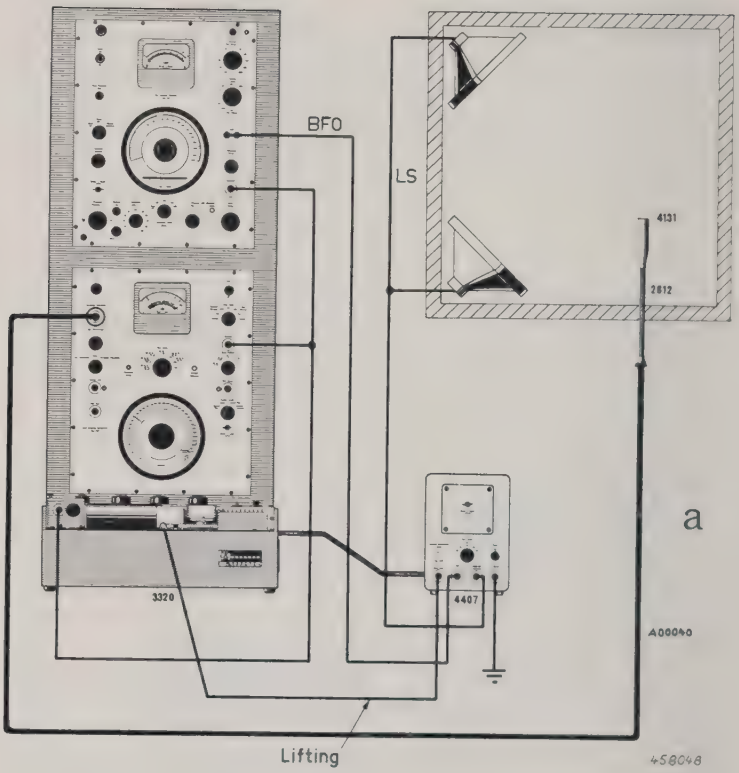
Fig. 44. Measurement of reverberation time.

However, a warble tone generator might replace the white noise generator as sound source, and when a series of measurements are to be taken at different frequencies this method will prove to be most convenient. Furthermore, it enables the measurements to be carried out automatically. Also in this case, though it might not be strictly necessary, it is recommended to employ the technique of selective measurements. A much larger level range can then be employed for the recording of reverberation curves, thereby facilitating a more accurate evaluation of the measured results.

Fig. 45a shows a measuring arrangement employing the A. F. Response and Spectrum Recorder Type 3320.

The B. F. O. of 3320 should be frequency modulated and the on-off switching of the sound source is remotely controlled from the Reverberation Switch Type 4407.

It may be mentioned that a suitable modulation frequency for the measure-



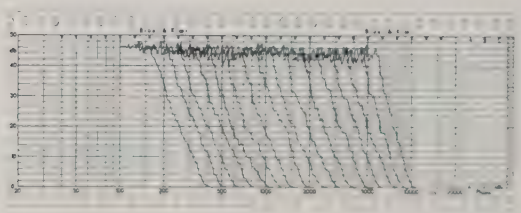


Fig. 45. Automatic recording of the reverberation time.

a. Measuring arrangement.
b. Recording obtained with the set-up shown in a.

ments ought to be within the limits 4/T and 10/T c/s, where T is the reverberation time to be measured. The bandwidth is normally ⅓ octave for the frequencies at which measurements are carried out, that is the modulation swing should be approx. ± ⅙ octave. However, an increase in the absolute bandwidth is not necessary at higher frequencies so that the maximum modulation swing of ± 200 c/s is sufficient, even where measurements are taken up to 20000 c/s. The above mentioned data are based upon the assumption that as many eigentones as possible should be excited in the room in which measurements are taken.

Following these instructions a reverberation curve will in most cases be obtained with only small fluctuations, the curve approximating to a straight line.

A well defined reverberation time can be found in this way for each frequency at which measurements are carried out.

The use of the Automatic Reverberation Switch enables an automatic recording of reverberation curves at different, pre-selected frequencies, see also the instruction manual for Type 4407.

The loudspeaker and microphone should be placed as far from each other as possible. Furthermore, the position of the loudspeaker and the microphone should be such that a direct transmission from loudspeaker to microphone is reduced to a minimum.

To eliminate the risk of recording a direct echo the microphone should not be placed too close to a wall. If this requirement cannot be met a piece of sound absorbing material should be mounted on the wall directly behind the microphone. The Spectrometer should be synchronized with the B. F. O., and care must be taken not to overload the apparatus at any time during the measurement.

If the switch on the front panel of Type 4407 is set to position "4.8", the wheel marked D used for the speed of the frequency sweep of the B. F. O. and Spectrometer, and the paper speed chosen to be 30 mm/s, reverberation curves with a distance of ⅓ octave will be recorded. In this case it is possible to employ frequency calibrated paper for the recording. The synchronization of 4407 with the A. F. Response and Spectrum Recorder must then be carried out carefully. A method of synchronization which has proved to be very useful is the following:

The recording paper is synchronized with the scale pointed of the B. F. O. as described in the instruction manual for the Beat Frequency Oscillator, Type 1014, and the automatic switch of Type 4407 is positioned such that in the moment the Level Recorder motor is started, the sound source is cut off. The position of this switch is very critical as the paper and the B. F. O. scale pointer moves with different speeds, and if the cut-off of the sound source does not follow immediately when the motor is started the synchronization between the paper and the Oscillator is "lost".

Fig. 45b shows a recording obtained with the described measuring set-up.

When reverberation measurements are to be carried out at only a few frequencies, the Automatic Reverberation Switch Type 4407 need not be used. The sound source can then be switched off by means of the press-button marked "Oscillator Stop", or with the aid of a remote control device as described in the manual for Type 1014.

Typical recording of measurements carried out in this way are shown in fig. 46 a and b.

Fig. 46b also illustrates the use of the Protractor Type 2361, which has been designed to facilitate the determination of reverberation time from recorded decay curves, the reverberation time being defined as that time it takes the sound energy to decrease 60 db. The Protractor is divided in 4 sections, marked 75 db 10 mm/sec., 75 db 30 mm sec., 50 db 10 mm sec. and 50 db 30 mm/sec. Only when used in one of these 4 combinations it will give the reverberation time directly in seconds.

The Protractor is, as shown in the figure, used by placing the thick line, which indicates the left section line (the line closest to the B in Brüel & Kjær), over the recorded decay curves in such a manner that one of the horizontal

Fig. 46. Typical reverberation curves:
a. From reverberation measurements at 1600 c/s.
b. Evaluation of the reverberation time with the aid of the Protractor Type 2361.

lines on the recording paper passes through the centre of the Protractor. The reverberation time in seconds can then directly be read at the point where this horizontal line crosses the scale.

The decay curves should preferably be approximated into straight lines making it easier, even though the unavoidable fluctuations, to determine the average slope.

Have other paper speeds than 10 and 30 mm/sec. been used, the determined reverberation times should be multiplied or divided by factors of 10.

Examples.

Paper speed 100 mm/sec.: Use the sections 10 mm/sec., and divide the reverberation times by 10.

Paper speed 1 mm/sec.: Use the sections 10 mm/sec. and multiply by 10.

If a 25 db potentiometer has been applied for the recording a section marked 50 db should be used and the determined reverberation times be divided by 2.

Measurement of Impact Sound.

The sound insulation of a floor against impact sounds is estimated by placing a standardised impact sound generator on the floor, and measuring the sound intensity L in the room below for various frequency bands. In the "Tentative Standards" for these measurements it is recommended to use $^1/_3$-octave filters for the estimation of the sound pressure, and it is recommended that the results be given in the form of a curve as a function of frequency or in tabular form as shown in fig. 47. The effective tapping level in a specific frequency band will then be given by the equation

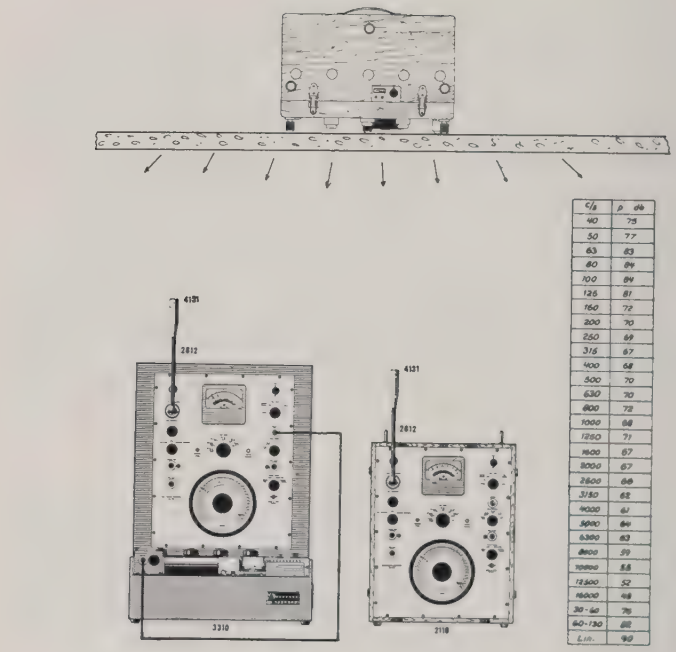
$$L_{eff} = L - 10 \log \frac{T}{0.5}$$

where T is the measured reverberation time in seconds in the receiving room in the frequency band in question. If one wishes to express the tapping level by a single figure L_A this can be calculated by means of a known described method, but it is always recommended to take a spectrogram of the sound under the floor in question, as this spectrogram is very important for judging the floor's quality.

Insulation Measurement of Airborne Sound with an Impact Sound Generator.

Fig. 48 shows a handy and simple method for the measurements of airborne sound insulation of walls and floor partitions in buildings.

The air-borne sound insulation of the partition between room 1 and room 2 is measured by producing a high sound level containing almost all acoustical frequencies by placing an impact sound generator on a wooden board which again is placed on springs, so that the total sound energy from the impact sound generator is radiated as air-borne sound and only a small amount as impact sound.



c/s	p dB
40	75
50	77
63	83
80	84
100	84
125	81
160	72
200	70
250	69
315	67
400	68
500	70
630	70
800	72
1000	68
1250	71
1600	67
2000	67
2500	66
3150	62
4000	61
5000	64
6300	63
8000	59
10000	58
12500	52
16000	48
30 - 60	76
60-120	82
Lin.	90

Fig. 47. Measurement and analysis of impact sound.

With the Spectrometer and the Condenser Microphone the sound pressures at different frequencies are first measured in room 1 and then in room 2. From the difference between the two readings the air-borne sound insulation D is found as a function of the frequency, when correction is made for the absorption of the receiver room according to the formula

$$D = 20 \log \frac{p_1}{p_2} + 10 \log \frac{F}{A_2}$$

where F is the area of the wall between room 1 and 2 and A_2 the absorption of the receiver room, both measured in the same units.

If the sound pressure of the noise as a function of frequency is recorded in the two rooms, the sound pressure relation between the two rooms can be directly estimated from the difference between the two curves, and thus the figure for the wall's insulation, D.

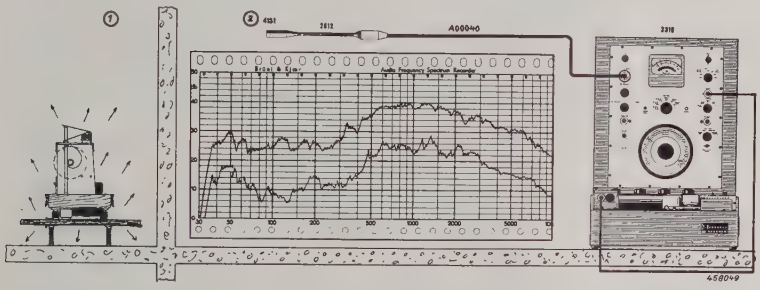


Fig. 48. Measurement of airborne sound insulation by means of "white noise".

Absorption Measurements on Sound Insulating Materials.

The sound absorbing properties of different materials may be evaluated from reverberation measurements, or a direct measurement of the absorption coefficient can be carried out with the aid of the Standing Wave Apparatus Type 4002. As shown in fig. 49 the Beat Frequency Oscillator Type 1014 feeds a loudspeaker, mounted at the end of a measuring tube. The frequency of the B. F. O. is kept constant during each measurement, and the measuring tube is terminated by the acoustical sample to be tested. Because of the reflection of the incident sound wave from the sample under test a standing wave pattern is set up in the tube.

If the termination of the tube consisted of a rigid wall, a complete reflection of the sound wave would be obtained. The result would be a pure standing wave with minima equal to zero. Absorption at the termination causes only a part of the wave to be reflected, and the minima will no longer be zero. The ratio between maxima and minima is determined exclusively by the absorption of the terminating material. This ratio can be found by measuring two successive maximum and minimum values of the sound pressure with a probe microphone. The microphone is shielded in a housing which is mounted on wheels and runs along a track in such a manner that the probe may be positioned anywhere along the central axis of the tube.

To avoid the influence of noise and harmonic distortion, which might occur when the absorption coefficient of the sample to be tested is small, the

measurement should be carried out selectively. The output voltage from the microphone is therefore fed to the input of the Spectrometer, Type 2110.

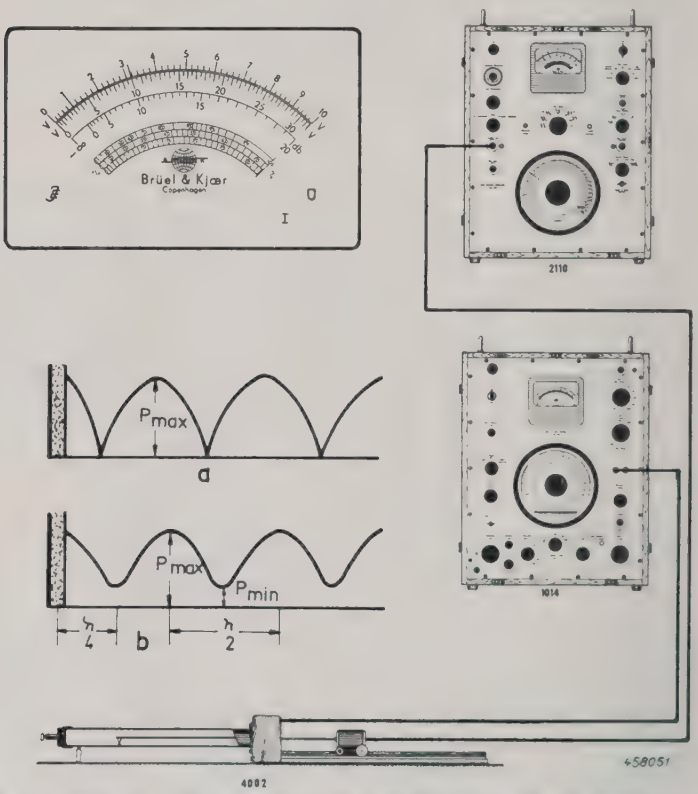


Fig. 49. Measurement of the acoustic absorption coefficient by means of the Standing Wave Apparatus Type 4002.

At the top of the figure the instrument meter scale is shown. Three different scales are provided for the measurement of absorption coefficients and are gradated from 0—100 %, 0—70 %, and 0 to 30 %.

The measurements are carried out as follows:

The Microphone is placed in a position where maximum sound pressure exists, and the gain of the Spectrometer adjusted until 100 % is read off the meter absorption scale.

The microphone is then positioned to indicate a minimum sound pressure. The meter now indicates the absorption percentage directly.

An increase in sensitivity of 10 or 20 db, respectively, allows the absorption coefficient to be read with greater accuracy on the scales calibrated from 0—70 % and 0—30 %.

Recording and Analysis of Fluctuating Noise.

In many workshops or offices the noise level varies considerably with time and if the noise level is measured in such places by means of a single reading, a serious error might be introduced. In such cases it is necessary to record the noise level over a relatively long period of time. A satisfactory average figure can then be obtained and noise peaks be observed, which are of particular interest from a health point of view. With an equipment consisting of a Condenser Microphone and the Audio Frequency Spectrum Recorder Type 3310 two different methods can be employed.

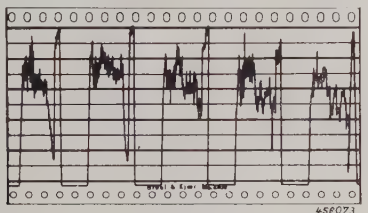


Fig. 50. Continuous recording of spectrograms and noise levels.

1. A series of Spectrograms can be taken, one after another. See fig. 50. When a sufficient number of Spectrograms has been obtained for a given room or workshop, they can be compared and the maxima determined for the different frequencies. Measurements of this type takes time (the time necessary to obtain one of the Spectrograms shown in fig. 50 was approx. 24 sec.) and almost as accurate results can be obtained by employing method 2.
2. Only one Spectrogram is taken, allowing the Spectrometer to measure each individual frequency band in a fairly large period of time. A spectrogram

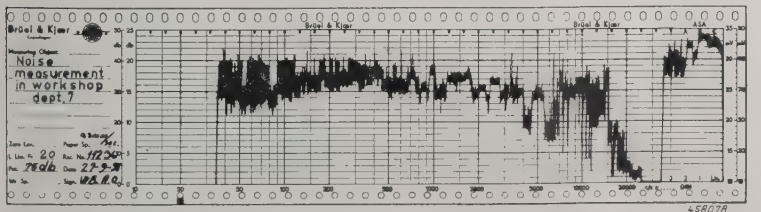


Fig. 51. Long time recording of spectrograms and noise levels.

obtained in this way is shown in fig. 51, using approx. 20 minutes for the complete recording.

If extremely accurate measurements are required, a combination of method 1 and 2 can be employed, i.e. measurements should be taken over one or two days with about three complete recordings per hour.

Production Line Testing of Domestic Apparatus with Regard to Noise.

An example of the use of the Audio Frequency Spectrum Recorder Type 3310 in production line testing is given in the following.

Fault in rotating machinery might be detected by the sound radiated. Extremely high peaks of sound at certain frequencies often give the tester a good idea of where to look for the fault. At the same time noise control can be performed when spectrograms are taken of the machinery under consideration.

The measurements can be carried out as shown in fig. 52. In two measuring chambers, acoustically treated to give the same response, Condenser Microphones are installed. The rooms must be well isolated from airborne as well as from impact sound.

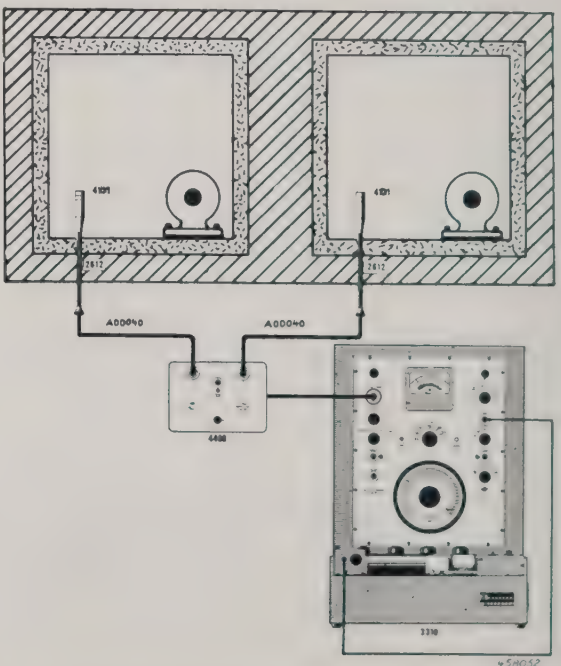


Fig. 52. Production line noise control of domestic apparatus.

Employing a Two Channel Microphone Selector Type 4408, the switching-over from measurements taken in one of the chambers to measurements to be taken in the other is readily carried out.

It is therefore possible to replace the apparatus tested in room 1, while measurements are carried out on the apparatus mounted in room 2, and a quick and reliable check on the acoustical performance of the equipment is obtained. Typical apparatus to be checked in this way, are relatively small electric motors, refrigerators, vacuum cleaners etc.

Automatic Recording of Harmonics.

By employing a low distortion oscillator such as the B.F.O. Type 1014, of the Automatic Frequency Response Recorder Type 3302 (3302 = B.F.O. 1014 + Level Recorder 2304) and the Spectrometer 2110 an automatic recording of the harmonics produced in an electronic or electro-acoustical equipment can be achieved.

Fig. 53a shows a measuring arrangement for investigating harmonic distortion produced in hearing aids. Usually the distortion produced in the electronic part of such a device (the hearing aid amplifier) is small as compared with the distortion caused by the electro-acoustical transducing elements.

The measuring arrangement shown includes for this reason the electro-acoustical system of the hearing aid, and fig. 53b shows a recording of the harmonics produced in the device.

The hearing aid is placed in the Hearing Aid Test Box Type 4212, which consists of a small anechoic chamber with built-in loudspeaker and regulating microphone,—as well as an artificial ear. The chamber itself is effectively insulated against both airborne and impact noise, and measurements can be taken at sound pressure levels down to approx. 50 db.

The regulating microphone and the hearing aid being tested should be placed symmetrically in the sound field. The regulating microphone then enables the reference level at the hearing aid to be kept constant, without influencing the practically free sound field condition, existing in the Test Box.

The hearing aid receiver is placed in the artificial ear whereby it is possible to measure the characteristics of the device with acoustic input and acoustic output.

In the measuring arrangement shown the Microphone Amplifier Type 2603 is used as "compressor amplifier", i.e. it is used to amplify the output voltage from the regulating microphone and feeding the amplified signal to the compressor input of the Oscillator.

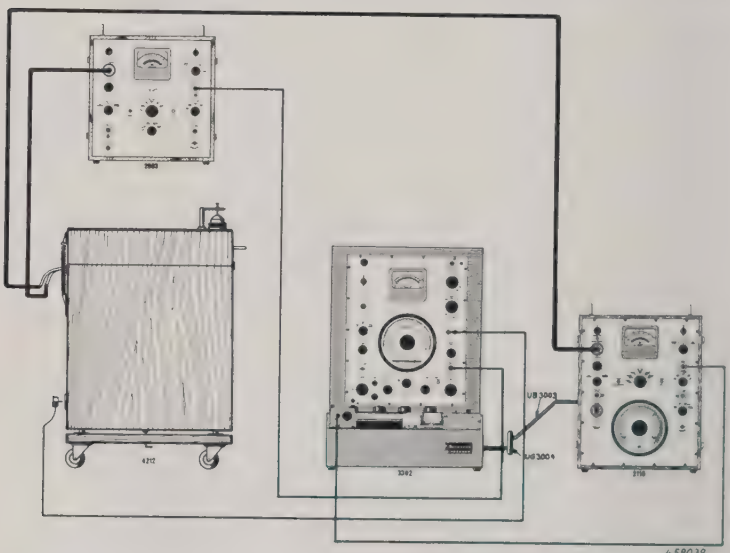
The filter switch on the front-panel of the Amplifier should be in position "20—35000 c/s - Curve C". It is now possible to read directly the sound-pressure in front of the hearing aid, as follows: By reading the positions of the "Meter Range" and "Range Multiplier" switches, as well as the meter deflection itself, the input voltage to the Amplifier is found. If the input voltage is X mV, and the sensitivity of the Condenser Microphone used as

regulating microphone is S mV μ/bar, the sound pressure in μbar is:

$$\text{S.P.} = \frac{X}{S} \ \mu\text{bar}.$$

Furthermore a mechanical connection is made between the Spectrometer and the Level Recorder of 3302 employing a Flexible Shaft UB 3003.

Where harmonics of a four-terminal network are to be recorded automatically it will, in most cases, prove to be advantageous to make an "endless



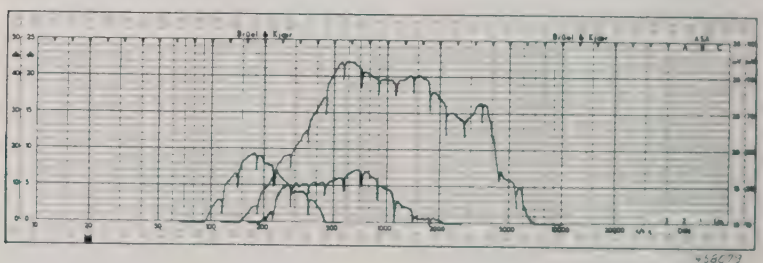


Fig. 53. Measurement of the harmonic distortion in hearing aids.
a. Measuring arrangement.
b. Recording of the fundamental and the second and third harmonic of a typical hearing aid.

loop" of the recording paper. The length of paper must then correspond exactly to one complete revolution of the scale pointer of the B.F.O. or Spectrometer i.e. 240 mm.

The following procedure should be employed:

1. The Spectrometer is synchronized with the "normal" frequency calibrated paper.
2. The scale pointer of the B.F.O. is synchronized with the frequency calibrated paper without disturbing the already obtained synchronization between the paper and the Spectrometer.
3. The "normal" paper is replaced by the "endless loop" and the "loop" is synchronized with the scalepointer of the B.F.O.
4. The motor in the Level Recorder is started and the fundamental ("1st harmonic") is recorded.
5. When the B.F.O. has traversed the frequency range once the motor is switched off and the scale pointer of the Spectrometer moved three filters ahead manually.
6. Start the motor in the Level Recorder again. By traversing the frequency range the curve recorded on the paper indicates the level of the second harmonic.
7. To obtain a recording of the 3rd harmonic the motor is stopped and the scale pointer of the Spectrometer manually advanced by further two filters. However, the center frequency of the filter employed will not then be a full multiple of the fundamental frequency indicated on the B.F.O. e.g. if the fundamental frequency is 100 c/s the center frequency of the filter used for recording the third harmonic is approx. 315 c/s.
   The result of this slight inaccuracy is that the Spectrometer is automatically switched to a new filter before the B.F.O. is tuned to a frequency, the third harmonic of which is inside the band-limits of the new filter. A part of the curve is thereby "lost".
   To compensate for this the B.F.O. should be tuned manually to a 5 % higher frequency, a correction which should be taken into account when evaluating the measured results from the recording paper.
8. The motor is started, and the third harmonic recorded.
9. To record the 4th and 5th harmonic the B.F.O. must be readjusted i.e. tuned back to the original synchronization.
   A recording of the 4th harmonic is then obtained when the scale pointer of the Spectrometer is manually advanced by one filter. A further advance of one filter permits the 5th harmonic to be recorded.

The sensitivity of the Spectrometer + Level Recorder should not be changed during the measurements. However, if a sensitivity greater than the one originally chosen is required to obtain a good recording of some of the harmonics, the gain of the Spectrometer can be increased by means of the "Range Multiplier" switch. This must then, of course, be taken into account when evaluating the final results.

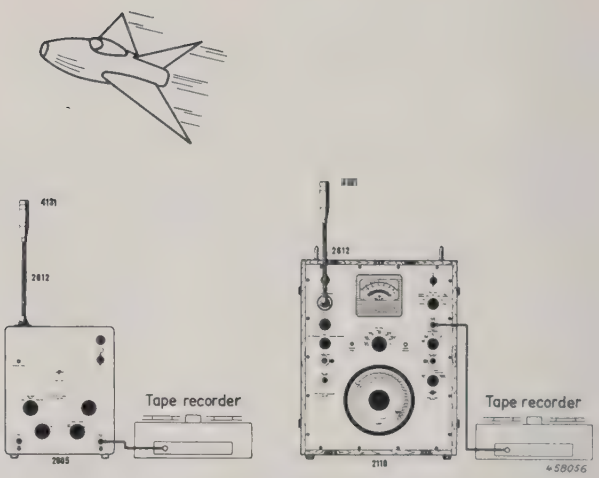


Fig. 54. Tape recording of transient noise.

Analysis of Transients.

An interesting application of the Audio Frequency Spectrum Recorder Type 3310 is the analysis of transients, which makes it possible to obtain the transient level not only as a function of time, but also as a function of frequency.

This kind of analysis has proved to be of considerable value when transients of noise from rockets, guided missiles, low flying aircrafts, motor vehicles etc. are investigated. Furthermore, it is often desired to obtain the amplitude-frequency-time relationship of the noise produced by periodically working machinery such as drilling machines and large Diesel engines. When acoustical transient phenomena are investigated a measuring arrangement as shown in fig. 54 and fig. 55 can be employed.

The pick-up device consists of a Condenser Microphone, a microphone amplifier e.g. Type 2605, and a tape recorder. The quality of the tape recorder should be high.

Instead of employing a Microphone Amplifier Type 2605, the Spectrometer can be used, then of course operating as a linear amplifier.

To obtain a reference signal on the tape for calibration the Noise Source Type 4240 should be used, see also the instruction manual for this instrument.

After having finished the recording of the noise on the tape recorder, the tape itself can be analyzed. See fig. 55.

The tape is folded as a loop and the ends are glued together.

The length of the loop should be accurately adjusted according to the time needed for the Spectrometer to switch from one filter to the other.

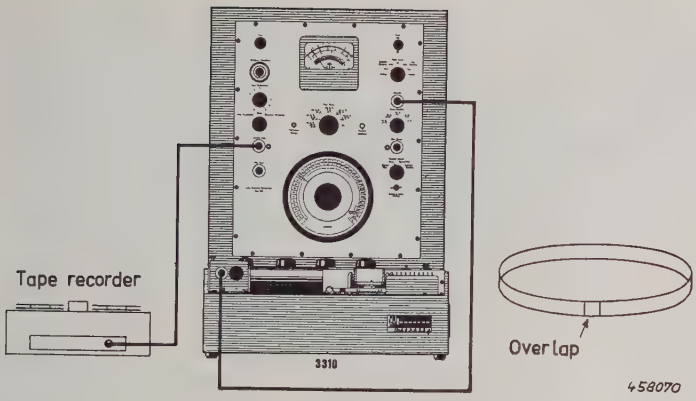


Fig. 55. Play-back of the tape for analysis.

In the following table the first row indicates the wheel position in the gear box of the Level Recorder, while the second row indicates the measuring time for each filter in the Spectrometer. The table is valid for Type 3310 and for the combination 2304 plus 2110, mechanically coupled together employing a Flexible Shaft UB 3003 and a Speed Multiplier UG 3004. The loop length is now the product of this time interval and the tape speed of the tape recorder.

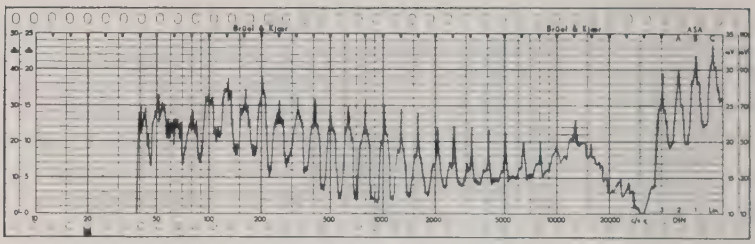
Table II.

Wheel:	A	B	C	D	E	F	G	H
Time per step:	0.48	1 6	4.8	16	48	160	480	1600 secs.
Paperspeed:	10	3	1	0.3	0.1	0.03	0.01	0.003 mm/sec.
Time for complete revolution:	0.4	1.33	4	13.3	40	133	400	1333 mins.

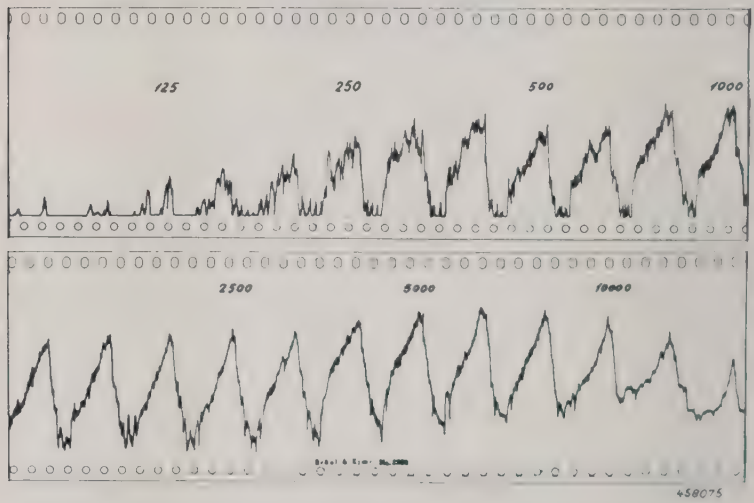
This results in a recording effacing the details of the transient noise per filter, but still enabling an over all view of the energy distribution over the whole spectrum.

To be able to adjust the length of the tape to its correct value, it is recommended to let the noise to be analyzed cover only approx. 75 % of the total loop length.

At a small distance from where the ends are glued together the tape can be touched by a small magnet, whereby a click is heard when playing it off. The first time this should be done without actually recording, only measuring the time taken for the loop to circulate a certain number of times. (Can be observed by means of the clicks heard). This time should then correspond to number of times $\times$ the interval time given in Table II. In case this requirement is not exactly fulfilled, the loop-length should be corrected.



a



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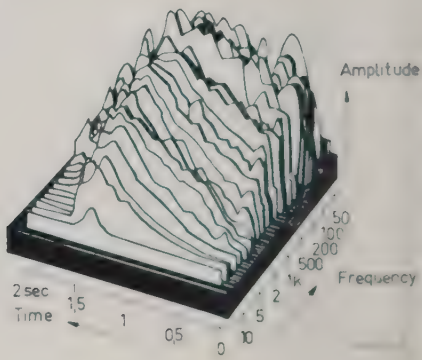

c

Fig. 56 Transient analysis of

a. A bang made in a small room.
b. A passing motorbicycle suddenly stopping.
c. Item b in a 3-dimensionel representation.

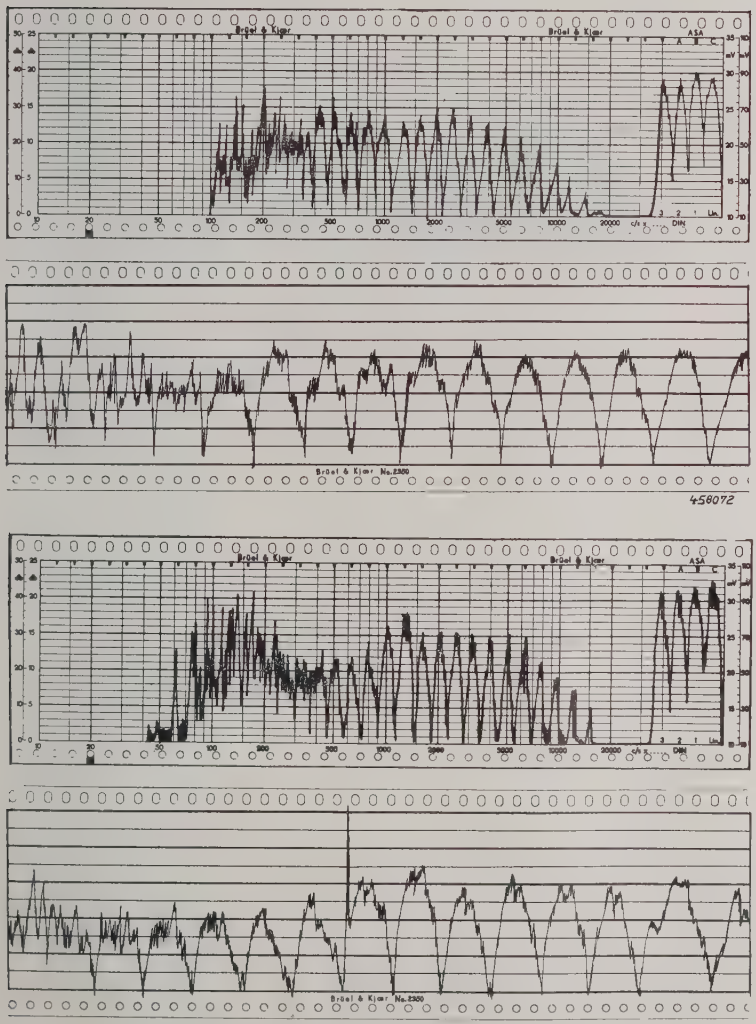

Fig. 57.

a. Noise from an automobile recorded at motor. Loop 91.5 cm, wheel C, P = 1 mm/sec, W = 300 db/s.

b. Id a. P = 3 mm/s.

c. Noise of an automobile recorded at exhaust-pipe, loop 91.5 cm, wheel C, P = 1 mm/s, W = 300 db/s.

d. Id c. P = 3 mm/s.

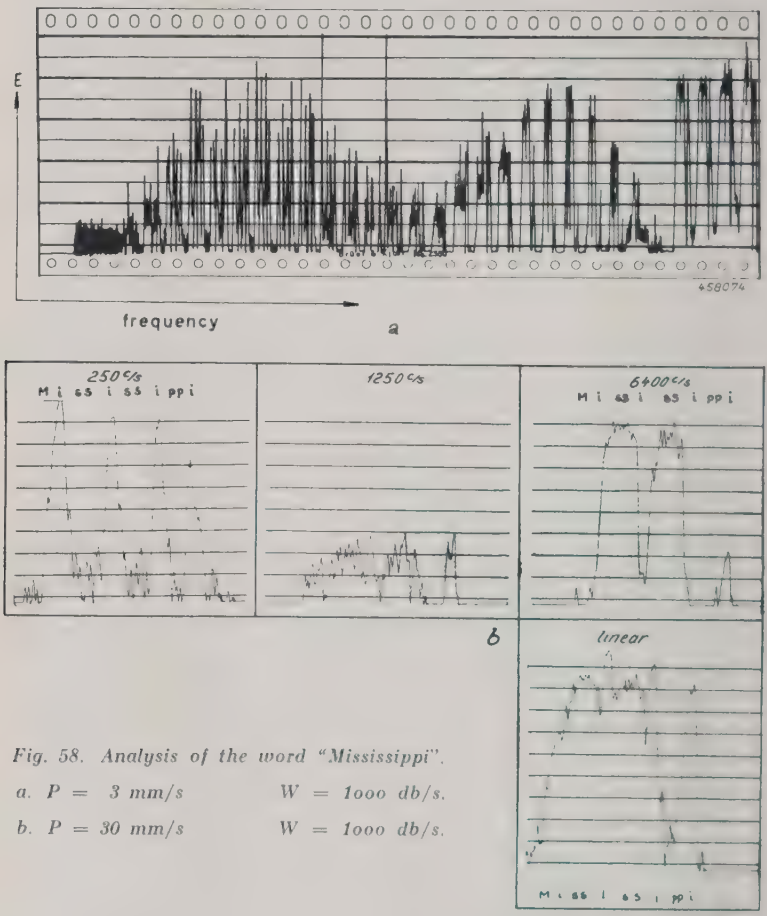

Fig. 58. Analysis of the word "Mississippi".

a. P = 3 mm/s W = 1000 db/s.

b. P = 30 mm/s W = 1000 db/s.

If recordings are made with higher paper speed than indicated in Table II, manual switching is recommended together with the use of paper type QP 2350, QP 2351 or QP 2352 without preprinting. To localize the frequencies of the different filters on the recording paper, some frequencies can be marked by means of the push button frequency mark on the Level Recorder.

In fig. 56, 57, and 58 a series of analyses of different sounds are shown. Fig. 56a shows the transient analysis of a bang made in a small room. The tape loop was in this case 30.5 cm long and was synchronized with the wheel

B and paper speed 3 mm/sec. so that paper with preprinted frequency scale could be employed. The writing speed was 300 db/s.

Fig. 56b is a recording without synchronization, the loop being of such a length that the transient noise from a passing motor-bicycle suddenly stopped could be recorded W = 300 db/s. P = 3 mm/sec. With a paper speed of 10 mm/s the "length" of recording per filter is sufficiently extended to make a 3-dimensional representation possible.

Fig. 56c shows a picture of such a 3-dimensional noise spectrogram.

In fig. 57 two noise analyses are shown, one recorded from measurements taken close to the motor of an automobile, the other is taken close to the exhaust pipe.

In both cases a synchronized as well as an extended recording were made (the latter is only partly shown).

Finally fig. 58 shows an analysis of the word "Missisippi". Fig. 58a indicates the energy distribution, and 58b shows the recording of some particular frequency bands. The energy distribution of the different sounds is clearly seen.

Appendix.

Some Notes on the Arithmetic Average, R. M. S. and Peak Rectifier.

The "value" of an AC signal may be expressed as the *arithmetic average value* of the signal, normally defined by the expression:

$$S_{a.a.} = \frac{1}{T} \int_{0}^{T} |s(t)| \, dt$$

where T is the time interval between two successively following moments of equal phase, see fig. 59.

A second method of expressing the value of the signal is by means of its *root mean square* (r.m.s.) *value* defined by:

$$S_{r.m.s.} = \sqrt{\frac{1}{T} \int_{0}^{T} (s(t))^2 \, dt}$$

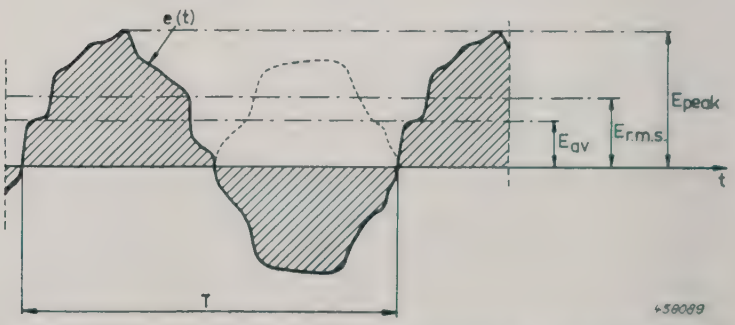

Fig. 59. Example of a periodic signal with indication of the peak, r.m.s. and arithmetic average value of the signal.

Finally, it is sometimes desired to know the max. value that the signal may reach within a certain time interval (a period), and this value is known as the *peak value* of the signal.

Fig. 59 indicates the significance of the above definitions with regard to a periodic signal of period T.

To obtain a meter indication on a measuring instrument which is designed to measure AC signals over a wide frequency range some sort of rectifier arrangement must be incorporated in the circuit. The rectifier then transforms the AC signal voltage into the DC voltage necessary to feed a moving coil meter.

It is now possible to give the rectifier circuit characteristics making the meter indication proportional to any one of the above mentioned "values" of the AC input signal.

The rectifier circuit employed in Type 2110 is designed, however, to enable not only the measurement of the arithmetic average, but also the true r.m.s. and the peak value of AC signals in the frequency range 2 to 35000 c/s.

In nearly all practical applications of the Spectrometer the r.m.s. indication will be the most important type of indication, because it has a direct connection to the energy contents of the signal being measured.

However, the possibility of measuring both the r.m.s. value and the arithmetic average value of complex signals is also of considerable interest in normal laboratory work. It is, for instance, possible by means of Type 2110 to establish correction factors for simple average type indicating voltmeters when applied to certain specific measurements of complex signals.

The measurement of signal peak values is convenient when the limiting effects of non linear electronic components are investigated.

Furthermore, from the measurement of the peak, the average and the r.m.s. value of a periodic signal the crest factor and the form factor of the signal can be calculated.

The crest factor is defined as:

$$f_c = \frac{S_{peak}}{S_{r.m.s.}}$$

and the form factor:

$$f_f = \frac{S_{r.m.s.}}{S_{average}}$$

From these expressions are readily seen that the crest factor of sharp periodic pulses must be high, while the crest factor, as well as the form factor for an ideal square-wave is exactly 1. It is thus possible, in some cases, by means of the crest factor and the form factor to obtain a rough picture of the signal wave shape.

Weighting Networks for Sound Level Measurements.

When measurements are taken with an equipment consisting of a microphone, amplifier and indicating meter having a linear frequency characteristic in the range 20 c/s to 20000 c/s (or higher) an indication of the absolute sound pressure level is obtained. This indication (in μbar) is useful for many physical investigations.

However, the sound pressure level measured with a linear frequency characteristic does not immediately give an indication of the human ear's perception of the sound's strength, because the ear is less sensitive to sounds of both low and high frequencies in comparison with the middle frequencies. This variation of sensitivity with frequency is very complicated as the absolute sound level also plays an important role. Sounds that seem to the ear to be equally loud are said to have the same subjective strength or loudness. Loudness is expressed in phons. In determining the loudness, the sound is compared with a tone of 1000 c/s whose physical energy is adjusted so that the sound and the 1000 c/s tone appear to the ear to be of equal strength. The loudness, expressed in phons, of the sound in question is then equal to the physical intensity of the 1000 c/s tone expressed in db above 2×10^{-4} μbars. At 1000 c/s, therefore, phon scale and decibel scale become identical, but at all other frequencies they will be different. Fig. 60 shows the sensitivity curves of the ear.

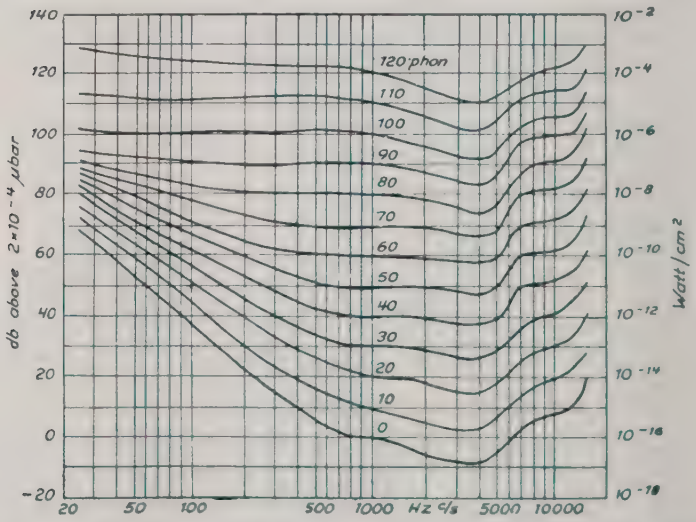

Fig. 60 The sensitivity curves for the human ear (Fletcher and Munson)

Accordingly the loudness in phons can only be found by subjective measurements, i.e. by means of the human ear.

However, an electrical instrument, such as a sound level meter, will give an indication of the sound level when equipped with filter networks depressing the high and low frequencies in a way corresponding to fig. 9. Sound levels measured with such an instrument should be expressed in db Sound Level, thereby stating the difference between subjective and objective measurements of loudness.

It has been found sufficient for practical sound level meters to use only three different filter characteristics, each effective within certain level limits.

The characteristics used in Europe are laid down in DIN 5045, and in America slightly divergent standards are laid down in ASA Z 24.3.

The tolerances permitted both for the European and the American standards are so great that it is possible to give an instrument frequency characteristics which satisfy both standard requirements. The standards also contain requirements for the sound level meter's dynamic characteristics, and overload safety factor. The Spectrometer 2110, when equipped with one of the B & K Condenser Microphones satisfies all these requirements within the permitted tolerances.

Weighted Spectrograms.

Almost every time a noise level measurement is taken it is necessary to analyze the frequency composition of the noise. However, a curve of sound

—	—	10	17	32	41	51	47	46	44	55	38	16	—	weighted Spectrogram
0	—	0	30	32	46	50	46	46	52	41	24	8		
36	38	47	40	45	47	51	47	46	44	52	37	26	20	real value db
54	32	31	47	43	48	50	46	46	50	39	32	22		

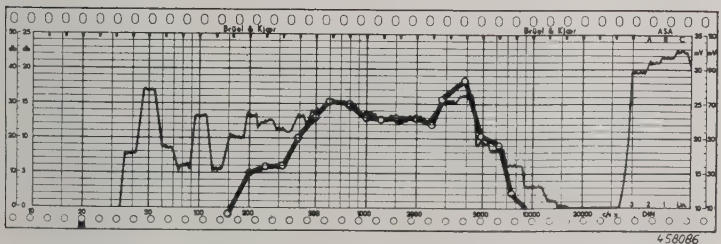

Fig. 61. Spectrogram of the noise from a grinding machine (fine line), and the same spectrogram weighted with reference to the sensitivity of the human ear (thick line).

pressure in μbar against the different frequencies cannot be used directly to judge the most disturbing frequency ranges. The spectrograms should first be corrected to the frequency sensitivity of the ear by means of the curves shown in fig. 60. When the spectrogram has been corrected in this way it is described as "weighted" with reference to the ear's sensitivity.

An example is shown in fig. 61, where the thin recorded curve shows the sound pressure as a function of frequency, for noise from a grindstone. The "weighted" curve is shown as round circles connected by a heavy line. It is clearly seen that the noise, which measured in μbar was strongest at lower frequencies, was most powerful in the middle range when judged subjectively, the lower frequencies having no importance for the human ear at the noise level in question.

Loudness and Loudness Level.

Loudness is a subjective quantity and cannot be measured exactly with any instrument. Loudness is defined as that aspect of auditory sensation in terms of which sound may be ordered on a scale running from "soft" to "loud". Loudness is chiefly a function of the sound pressure level, but is is also dependent on the frequency and the composition of the sound. The loudness of a sound is related to the total wave energy produced by the sound in the ear, whence it is sent to the brain.

The range of loudness is divided subjectively into equal unit steps called sones = 1000 millisones = 1000 loudness units. A loudness of 1 sone corresponds to a sound pressure level of 40 db re 2×10^{-4} μbar at 1000 c/s and a loudness of 10 sones is twice as loud as a loudness of 5 sones and 10 times as loud as 1 sone etc.

The loudness of a sound at a given sound pressure level at one frequency may be quite different from the loudness of a sound of the same level at a different frequency, but listeners can adjust the level of one tone to match the loudness of another. By such experiments a useful objective scale of loudness, called loudness level, is made.

Loudness level of a pure tone in phons is numerically equal to the sound pressure level expressed in db above 2×10^{-4} μbar of a 1000 c/s tone, which sounds equally loud.

Equal loudness contours for pure tones are shown in fig. 60.

The relationship between loudness in sones and loudness level in phons is given in fig. 62.

This curve applies to sound of any frequecy, or combination of frequencies If the loudness level of a sound is 40 phons, it will have a loudness of 1000 millisones, if the loudness level is 70 phons, it will have a loudness of 10 000 millisones. A reduction of the loudness level from 70 to 40 phons corresponds to a tenfold change in loudness.

This relationship is of considerable practical interest with regard to the reduction of noise in rooms by sound absorption or by sound insulation. It, for example, the loudness level in a workshop by acoustical treatment of the

ceiling is reduced from 72 phons to 63 phons, the average listener will judge the reduction from 12 to 6, which is the same as to the half or to 50 %.

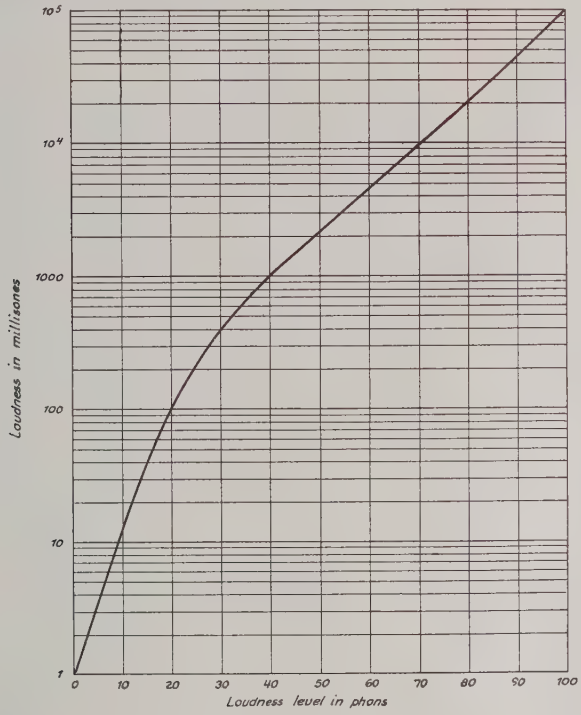

Fig. 62. Loudness in sones plotted versus the loudness level in phons.

Calculation of Loudness Level from Frequency Spectra.

If it is desired to calculate the loudness level in phons from a measured line spectrum consisting of a number of discrete frequencies, spaced relatively widely, the two charts figs. 60 and 62 are used. The procedure is as follows:

1) Determine from the chart fig. 60 the loudness level in phons of each discrete frequency according to the frequency, and sound pressure in μbar.

2) Take the loudness level in chart fig. 62 and find for each discrete frequency the corresponding loudness in millisones.

3) Add the different values for loudness.

4) Use this sum in fig. 62 to find the total loudness level in phons for the line spectrum.

For the calculation of loudness from continuous spectra (noise) is referred to B & K Technical Review No. 1 1956.

Audio Frequency Spectrometer

Type 2110

Specifications.

Frequency Characteristics:
"Linear": 2 c/s to 35000 c/s to within ± 0.5 db (± 0.3 db in the range 5 c/s to 20000 c/s).
Weighting Networks: Characteristics in accordance with A.S.A. Curve C — A.S.A. Curve B (DIN 1) — A.S.A. Curve A (DIN 2)) and DIN 3.
Band Pass Filters: Bandwidth ⅓ octave. Center frequencies from 40 c/s to 31500 c/s.
Sensitivity: Max. 100 μV full scale deflection. Min. 1000 volts. Variable in steps of 10 db.
Amplification: Max. 100 db. Amplifier noise referred to input and max. gain: Approx. 15 μV with open input and approx. 5 μV with short circuited input.
Input:
1. "Direct". Input Impedance 2.2 MΩ paralelled by 30 pF.
2. "Input Potentiometer". Input impedance approx. 1 MΩ. To be used for relative measurements.
3. "Condenser Microphone". 7-poled socket for the B & K Condenser Microphones, Artificial Ears, and Preamplifiers.
Output: "Recorder". Output impedance smaller than 50 Ω. Output voltage corresponding to full scale meter deflection approx. 10 V. Max. available output voltage approx. 30 V.
Meter: Conveniently illuminated instrument scales. Perfectly safeguarded against overload. Accuracy: Approx. 2 % of full scale deflection. Scales: 0—10 and 0—31 V (linear), 0—20 db (logarithmic) as well as 3 scales calibrated in % absorption for use in connection with the Standing Wave Apparatus Type 4002.
Two different meter damping characteristics: The characteristic standardized for sound level measurement, and heavy damping for the measurement of very low frequency signals.
Meter Rectifier: Peak — R.M.S. or arithmetic average type rectification can be selected by means of a switch.
Microphony: Careful selection of tube types and circuits as well as rubber suspension of critical components reduces the amplifier microphony to a minimum.

Polarization Voltage: The polarization voltage for the Condenser Microphone Cartridges can be adjusted between 150 and 250 volts.
Tubes: ECC81 (12AT7) — ECC83 (12AX7) — EF94 (6AU6) — 6U8 — EZ90 (6X4) — OA2 — OB2.
Power Supply: 155 — 127 — 150 — 220 — 240 volts AC. 50—60 c/s. Power consumption is approx. 50 watts.
Cabinet: Mahogany cabinet with handles and lid.

Dimensions excl. dials and knobs	Height	Width	Depth
Centimetres	51	40	20
Inches	20	16	8
Weight	30 kg		66 lbs.

Level Recorder Type 2304.

Specification

Frequency Range: From 20 to 200 000 c/s.

Zero Level: Adjustable from 5 to 14 mV. The instrument is supplied with a reference voltage of 10 mV.

Recording System: Patented moving-coil system.

Recording Speed: Variable in 9 steps from 1000 to 50 decibels per second with the 50 db potentiometer.

Damping of the Recording System: Feed back system giving max. restoring force.

Potentiometers:

The following Potentiometers are obtainable:		Accuracy
Type 2341	35 to 110 phons Noise Level Potentiometer ..	± 1 phon
» 2343	10 to 35 mV. Linear Potentiometer	2 % of full scale
» 2344	10 to 110 mV. Linear Potentiometer	2 % of full scale
2345	10 db Logarithmic Potentiometer	± 0,3 db
» 2346	25 db Logarithmic Potentiometer	± 0,3 db
» 2347	50 db Logarithmic Potentiometer (standard equipment)	± 0,5 db
» 2348	75 db Logarithmic Potentiometer	± 1 db

The Level Recorder is delivered at catalog-price with a potentiometer Type 2343—2348.

Paper: 65 millimeters perforated and lined waxed paper for scratching with sapphire stylus or usual recording paper for ink writing. Effective recording width 50 millimeters. A sapphire stylus and an ink pen are supplied. The paper is illuminated when the Level Recorder is in use.

Paper Speed: 10 different speeds. 100—30—10—3—1—0,3—0,1—0,03—0,01—0,003 millimeters per second.

Connection to other Instruments: Two rotating spindles can be given the following revolutions per minute: 75—22,5—7,5—2,25—0,75—0,225—0,075—0,0225 and 0,0075. The spindles rotate in opposite direction with respect to each other. To the rotating spindles may furthermore be connected the Two Channel Selector Type 4405.

Tubes: 4 × 6AU6 (EF94), 2 × 6AL5 (EB91), 2 × 6AQ5 (EL90), OA2, 150C2, 6X4 (EZ90).

European Model: Power supply: 115—127—150—220 volts a.c. 50 c/s. 70 watts.

American Model: Power supply: 115 volts a.c. 60 c/s. 70 watts.

Cabinet: Mahogany cabinet with handles and lid.

Dimensions excl. dials and knobs	Height	Width	Depth
Centimetres	23	51	23
Inches	9	20	12
Weight	28 kg		62 lbs.

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